

Quarkonia Production with Leptons and Hadrons

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- Introduction
- FNAL - past, present, and future
 - ◆ Tevatron (Run I/Run II): (J/ψ , $\psi(2S)$, χ_c , Υ , χ_b , η_b)
 - ◆ Fixed Target: (Υ polarization)
- HERA - past, present, and future
 - ◆ Inelastic production measurements (J/ψ , $\psi(2S)$)
 - ◆ Diffractive production measurements (J/ψ)
 - ◆ Fixed Target: (J/ψ , $\psi(2S)$, χ_c , Υ)
- Conclusions

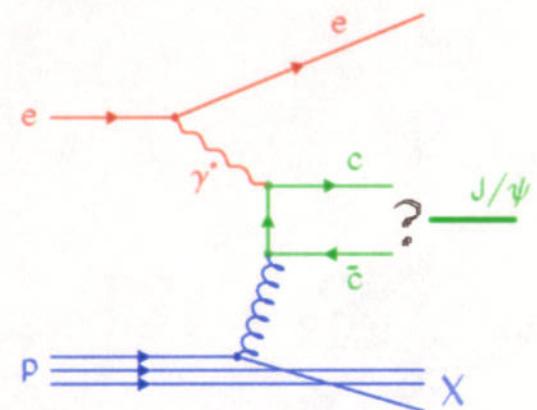


E866/NuSea



Introduction

- **Tevatron (Run I 1992-96, $\int L dt = 20 \text{ pb}^{-1}$ (IA) + 90 pb^{-1} (IB)):**
 - ◆ $p \rightarrow \bar{p}$ at $\sqrt{s} = 1.8 \text{ TeV}$
 - ◆ η, p_T , polarization
- **HERA ("Run I", $\int L dt = 100 \text{ pb}^{-1}$):**
 - ◆ $e^\pm (27.5 \text{ GeV}) \rightarrow \bar{p}$ ($820/920 \text{ GeV}$) at $\sqrt{s} = 300/320 \text{ GeV}$
 - ◆ Q^2, W, z, p_T, t, \dots , polarization
 - ◆ overconstrained kinematics
- **History**
 - ◆ Inelastic J/ψ production at HERA: a golden way to extract gluon density
 - ◆ Elastic/diffractive J/ψ production to measure luminosity
- **Variety of presumed production mechanisms:**
 - ◆ Diffractive/elastic
 - ◆ Gluon-gluon-fusion, photon-gluon-fusion
 - ◆ Gluon fragmentation
 - ◆ "Resolved photon"-gluon/quark-fusion
 - ◆ + decays



Publications (Most Recent Only)

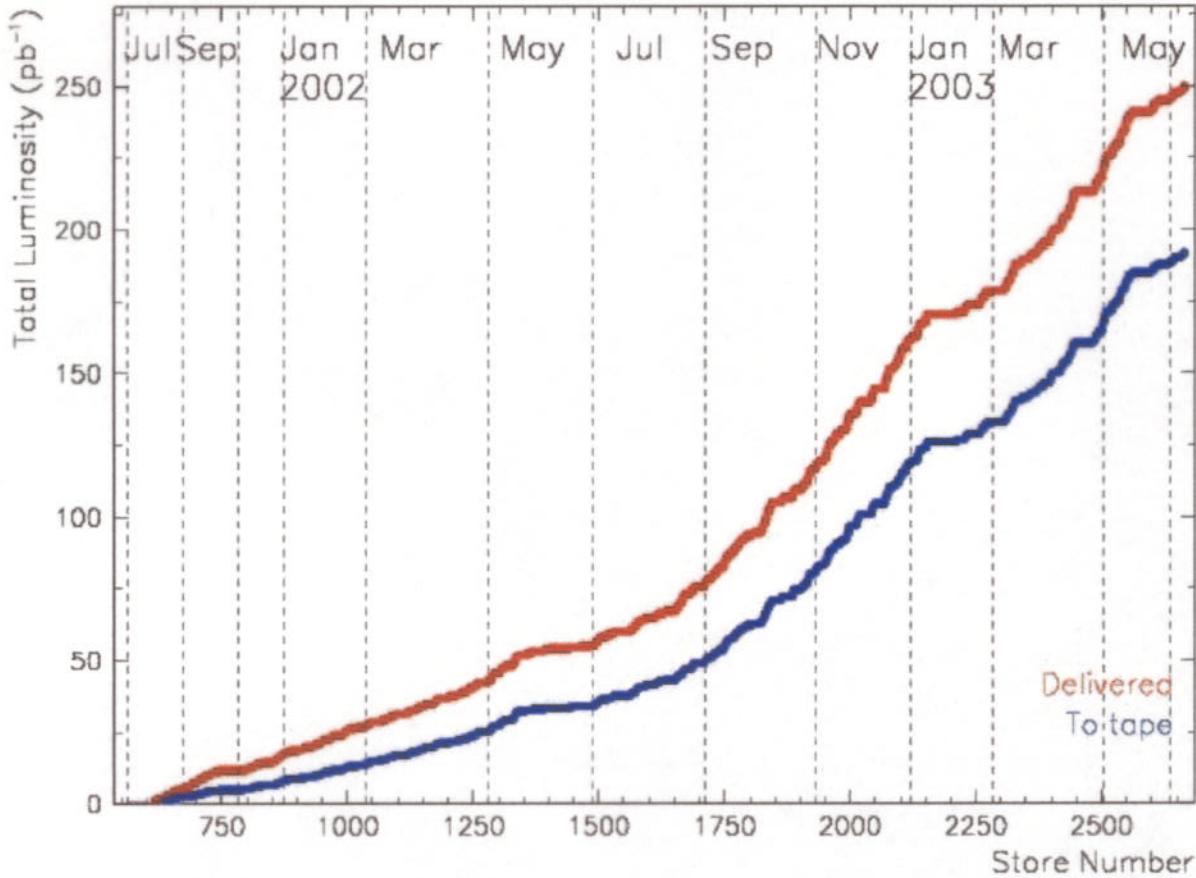
T
E
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J/ψ and $\psi(2S)$ cross section	CDF	(15 pb $^{-1}$)	PRL 79 (1997) 572
J/ψ cross section, $\chi_c \rightarrow J/\psi\gamma$	D0	(7 pb $^{-1}$)	PL B370 (1996) 239
$\chi_c \rightarrow J/\psi\gamma$	CDF	(18 pb $^{-1}$)	PRL 79 (1997) 578
χ_{c1}/χ_{c2}	CDF	(110 pb $^{-1}$)	PRL 86 (2001) 4472
Polarization J/ψ, $\psi(2S)$	CDF	(110 pb $^{-1}$)	PRL 85 (2000) 2886
"Forward" J/ψ	D0	(10 pb $^{-1}$)	PRL 82 (1999) 35
	CDF	(74 pb $^{-1}$)	PRD 66 (2002) 092001
Diffractive J/ψ	CDF	(80 pb $^{-1}$)	PRL 87 (2001) 251803
Polarization Υ pCu	E866	(2M dimuons)	PRL 86 (2001) 2529

H
E
R
A

J/ψ from χ_c (p-C, p-Ti)	HERA-B		PL B561 (2003) 61
Elastic/diffractive	H1	(78 pb $^{-1}$)	DESY-03-061
	ZEUS	(50 pb $^{-1}$)	EJ C24 (2002) 345
	H1	(20 pb $^{-1}$)	PL B483 (2000) 23
	H1	(27 pb $^{-1}$)	EJ C10 (1999) 373
	ZEUS	(6 pb $^{-1}$)	EJ C6 (1999) 609
	ZEUS	(25 pb $^{-1}$)	DESY-02-072 (\rightarrow EJC)
	H1	(77 pb $^{-1}$)	PL B541 (2002) 251
	H1	(27 pb $^{-1}$)	EJ C10 (1999) 373
Inelastic	H1	(88 pb $^{-1}$)	EJ C25 (2002) 25
	H1	(77 pb $^{-1}$)	EJ C25 (2002) 41
	ZEUS	(38 pb $^{-1}$)	EJ C27 (2002) 173

Luminosity Delivered and Recorded-CDF



Physics quality data
began March 2002
 $\sqrt{s} = 1.96 \text{ TeV}$

Delivered 225 pb^{-1}
Recorded 180 pb^{-1}
(80%)
83% since February

Summer Conference
140 pb^{-1} QCD
110-140 pb^{-1} EWK
100-110 pb^{-1} Top+
100-140 pb^{-1} Exotics
110 pb^{-1} Bottom

Since Feb 10 2003, silicon in 94% of time

Winter top analyses used 57 pb^{-1}

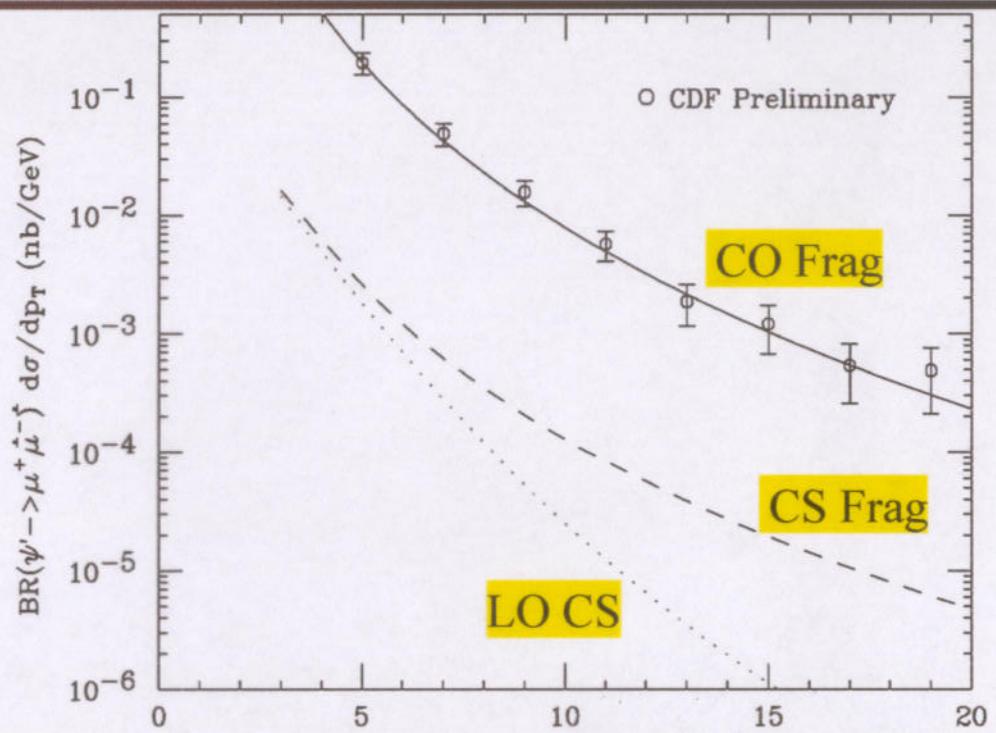
Direct $\psi(2S)$ Cross Section - CDF

- $\psi(2S) \rightarrow \mu\mu$, Run IA data, 18 pb^{-1}
- “Central muons” ($|\eta| < 0.6$)
- Lifetime information from SVX used to extract prompt component
- *Prompt* \equiv direct for $\psi(2S)$
- Colour singlet fusion: α_s^3/p_T^8
- CS fragmentation (Braaten, Yuan, PRL 71(1993) 1673): α_s^5/p_T^4

$$g^* \rightarrow 2g + c\bar{c}(^3S_1^{(1)}) \rightarrow \psi(2S)$$
- NRQCD expansion

$$d\sigma(H) = \sum_n d\sigma[c\bar{c}(n)] \langle O^H(n) \rangle$$

- ◆ n includes colour singlet and octet states
- ◆ Expansion in α_s and v (relative velocity of quark and anti-quark)

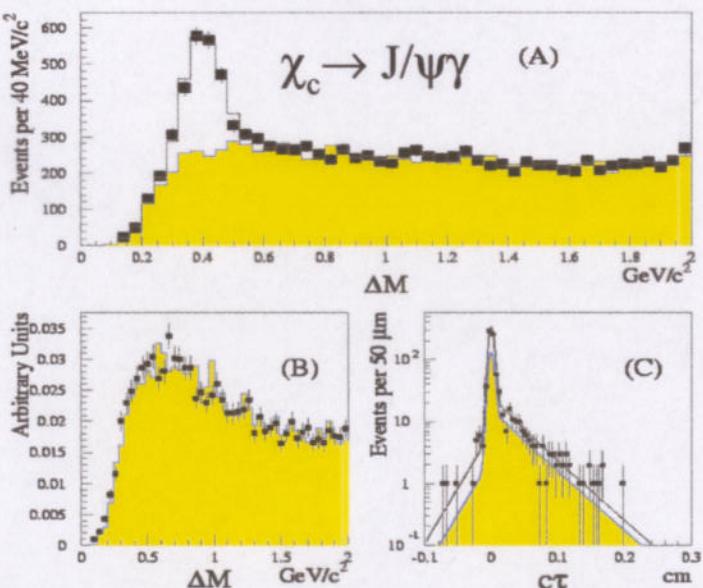
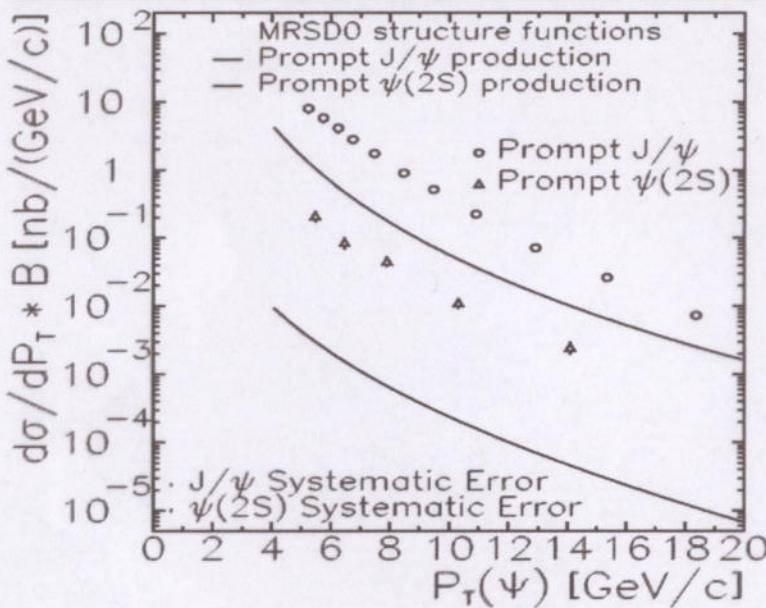


Braaten, Fleming PRL 74(1995) 3327
CDF Data: PRL 79(1997) 572

- Colour octet fragmentation (Braaten, Fleming, PRL 74(1995) 3327): $\alpha_s^3 v^4/p_T^4$

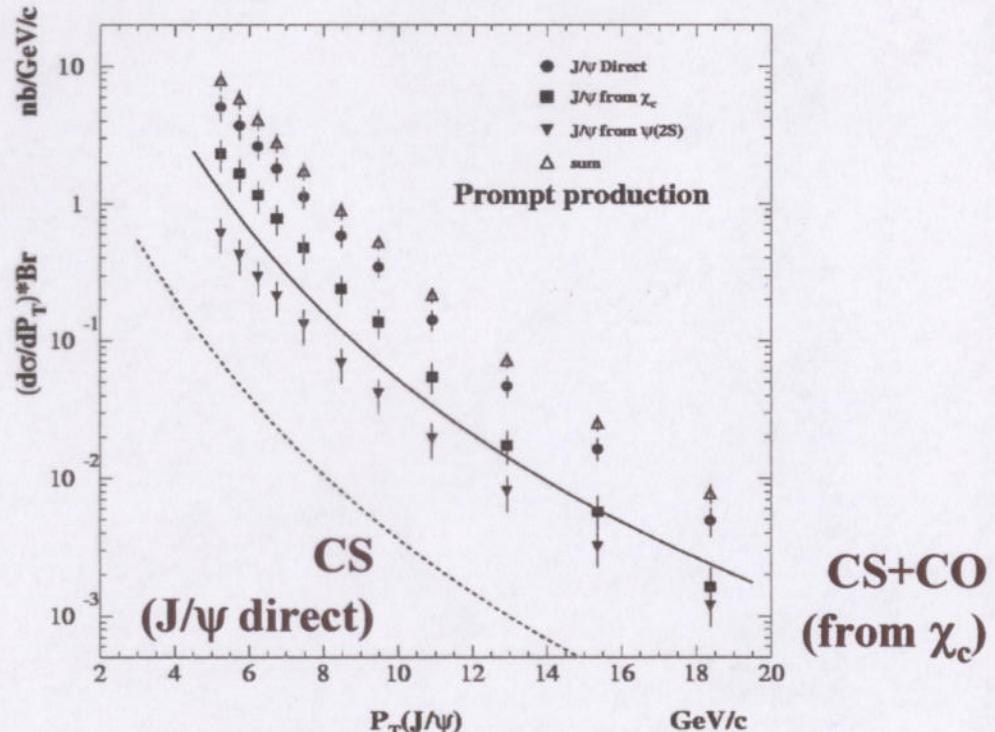
$$g^* \rightarrow c\bar{c}(^3S_1^{(8)}) \rightarrow \psi(2S)$$
- *Fragmentation dominates at high p_T*

Prompt / Direct J/ψ Cross Section



$J/\psi \rightarrow \mu\mu$

- Prompt J/ψ cross section includes
 - ◆ χ_c decays ($\chi_c \rightarrow J/\psi \gamma$ measured)
 - ◆ $\psi(2S)$ feed-down (measured)
 - ◆ Direct J/ψ ($64 \pm 6\%$)

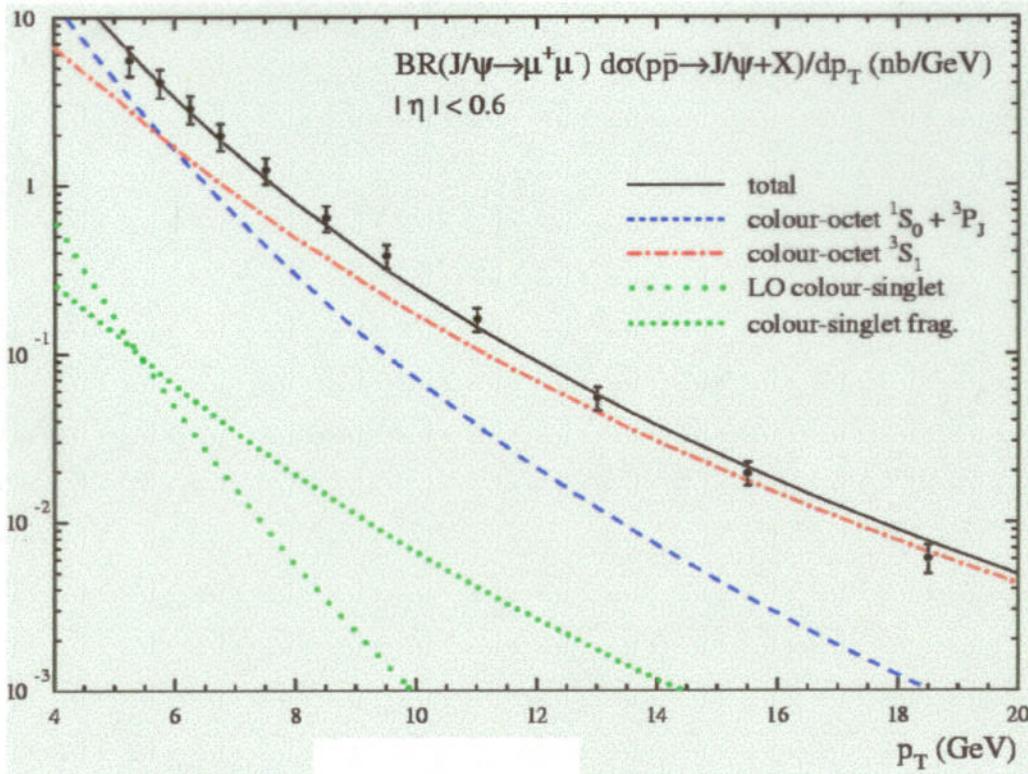


CDF, PRL 79(1997) 572, 578

June 28, 2003

Direct J/ψ Cross Section

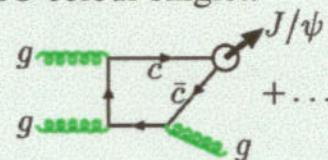
- Large uncertainties in the extracted matrix elements
 - ◆ low p_T : effects of gluon k_t
 - ◆ parton density functions



Beneke, Krämer, PRD 55(1997) 5269

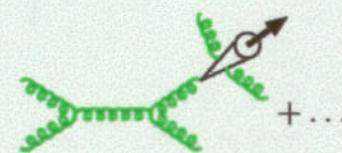
Vaia Papadimitriou (Texas Tech University)

LO colour singlet:



$$\sim \alpha_s^3 \frac{(2m_c)^4}{p_t^8}$$

colour-singlet fragmentation: $g + g \rightarrow [c\bar{c}^3S_1^{(1)}] + gg + g$



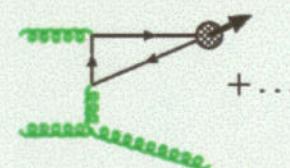
$$\sim \alpha_s^5 \frac{1}{p_t^4}$$

colour-octet fragmentation: $g + g \rightarrow c\bar{c}^3S_1^{(8)} + g$



$$\sim \alpha_s^3 \frac{1}{p_t^4} v^4$$

colour-octet fusion: $g + g \rightarrow c\bar{c}[1S_0^{(8)}, 3P_J^{(8)}] + g$

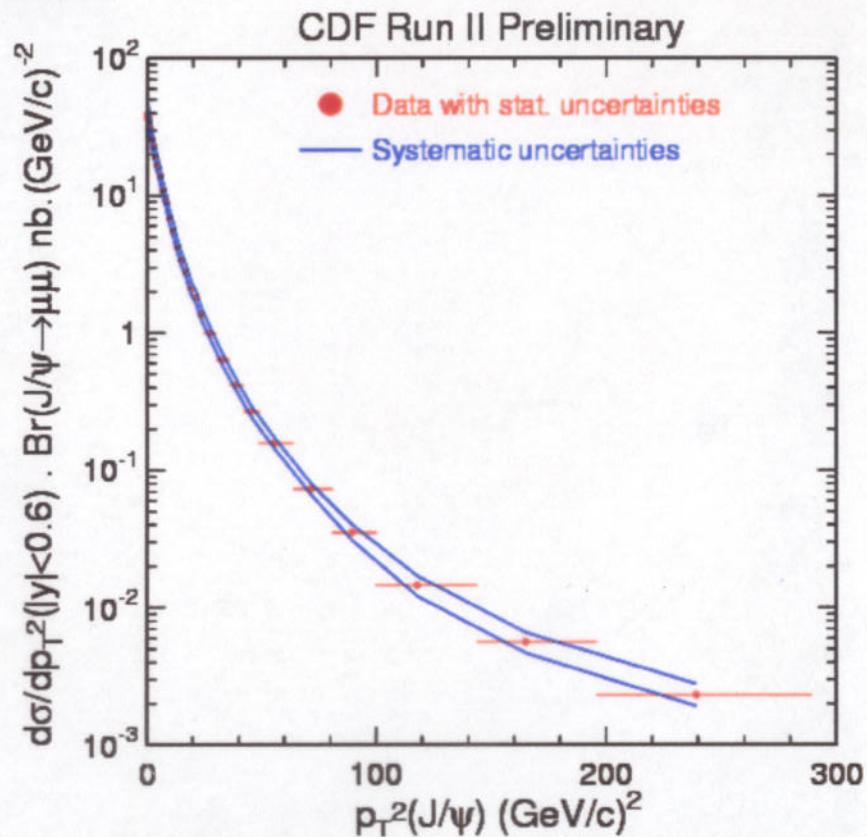
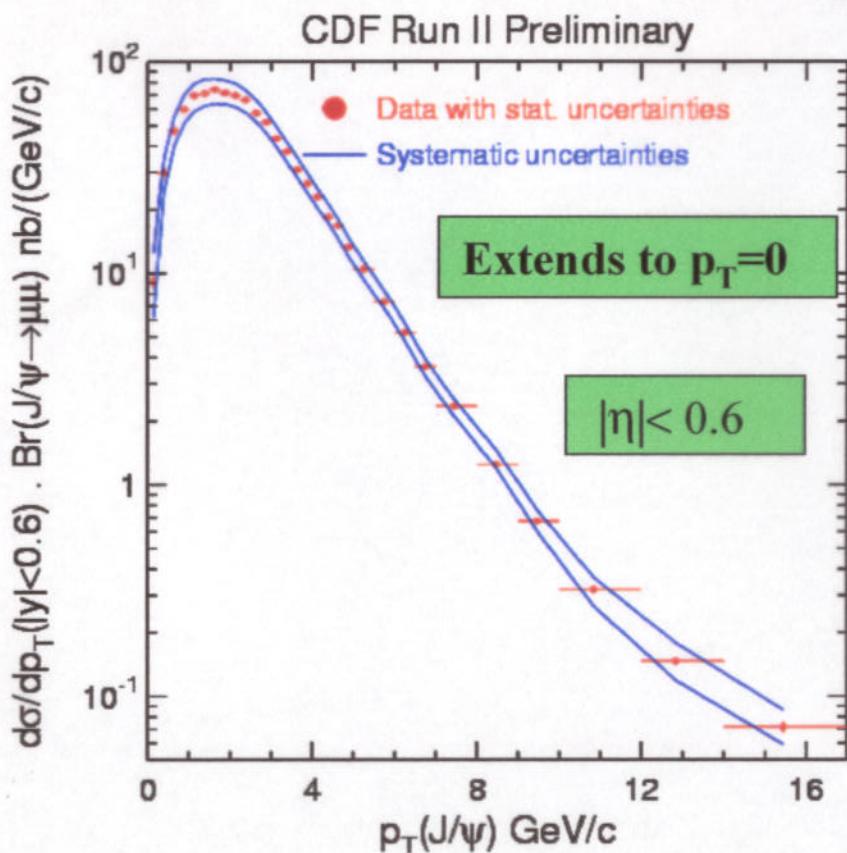


$$\sim \alpha_s^3 \frac{(2m_c)^2}{p_t^6} v^4$$

June 28, 2003

J/ ψ Cross Section – Run II

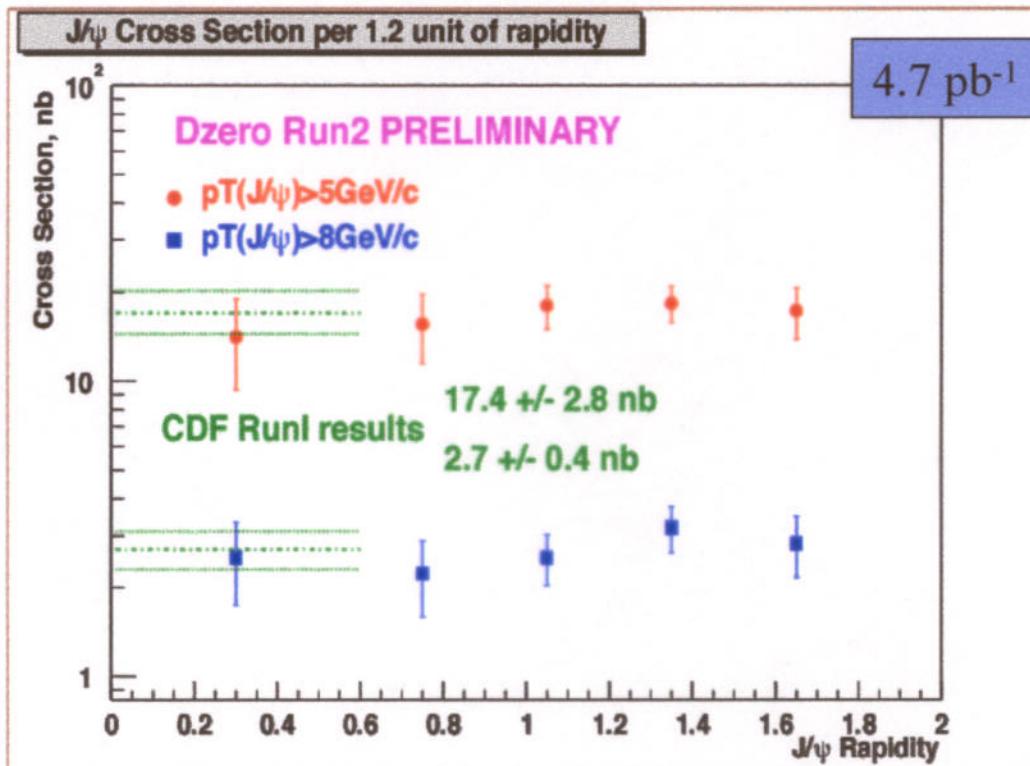
39.7 pb⁻¹



$$\frac{d\sigma_\psi}{dp_T} \bullet BR(J/\psi \rightarrow \mu\mu) = \frac{N'(p_T)}{\varepsilon_{rec} \bullet \Delta p_T^{bin} \bullet \int L dt}$$

$$\sigma_{p\bar{p} \rightarrow J/\psi} = 240 \pm 1(stat)^{+35}_{-28}(syst) nb$$

J/ ψ Cross Section - Run II



Cross section as a function of rapidity

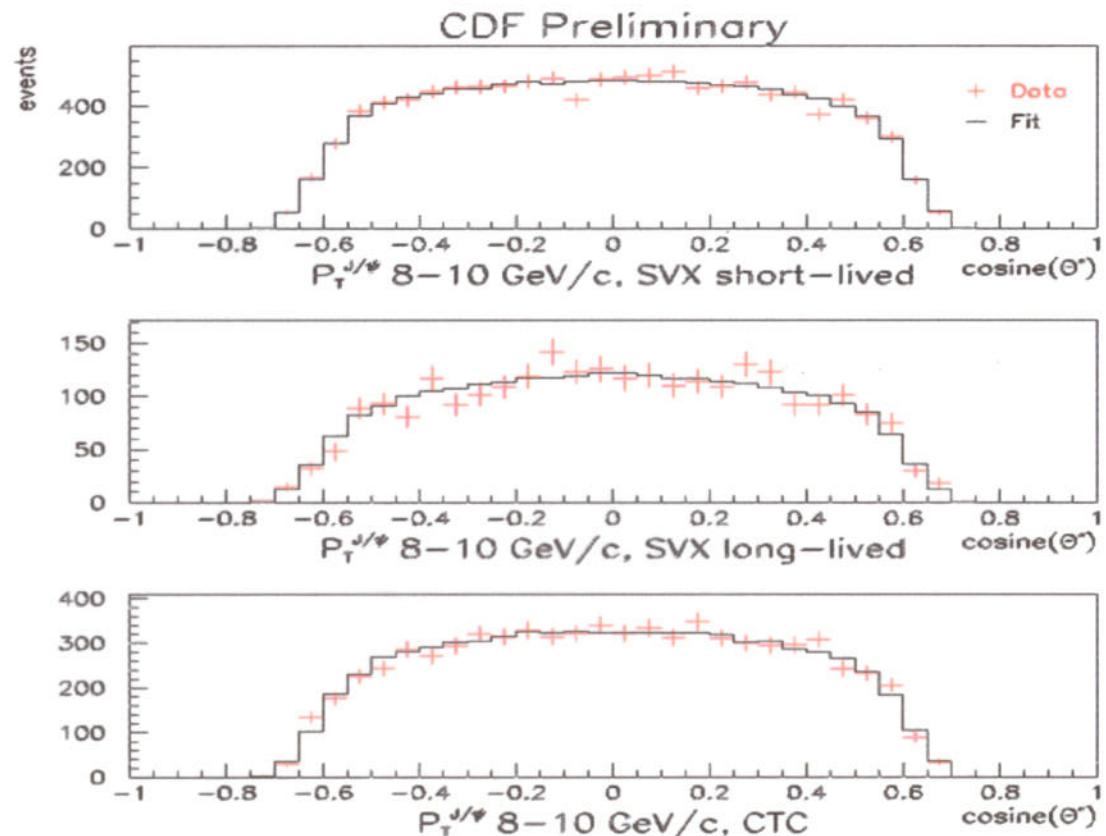
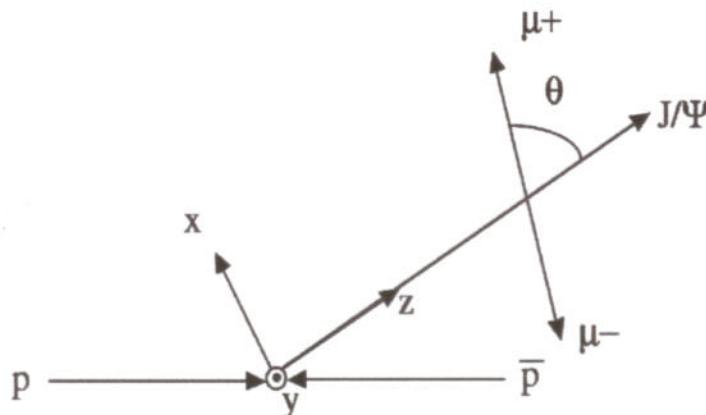
J/ψ Polarization

- All CDF Run I data, $\int L dt = 110 \text{ pb}^{-1}$
- $p_T > 4 \text{ GeV}$, $|y| < 0.6$
- Small acceptance at large $|\cos \theta|$
- χ^2 fit using templates for longitudinal and transverse polarization

$$d\Gamma/d\cos\theta \propto 1 + \alpha \cos^2\theta$$

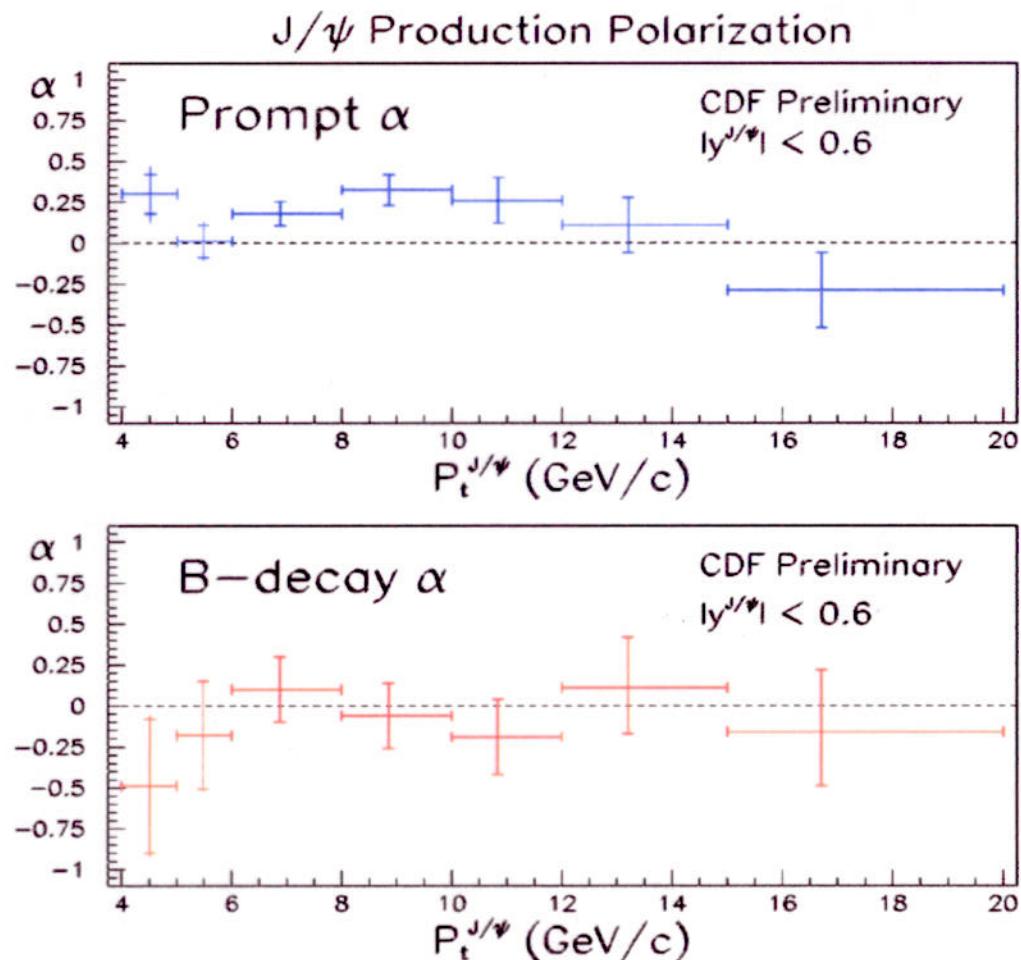
$\alpha = 1$ transverse

$\alpha = -1$ longitudinal



J/ψ Polarization

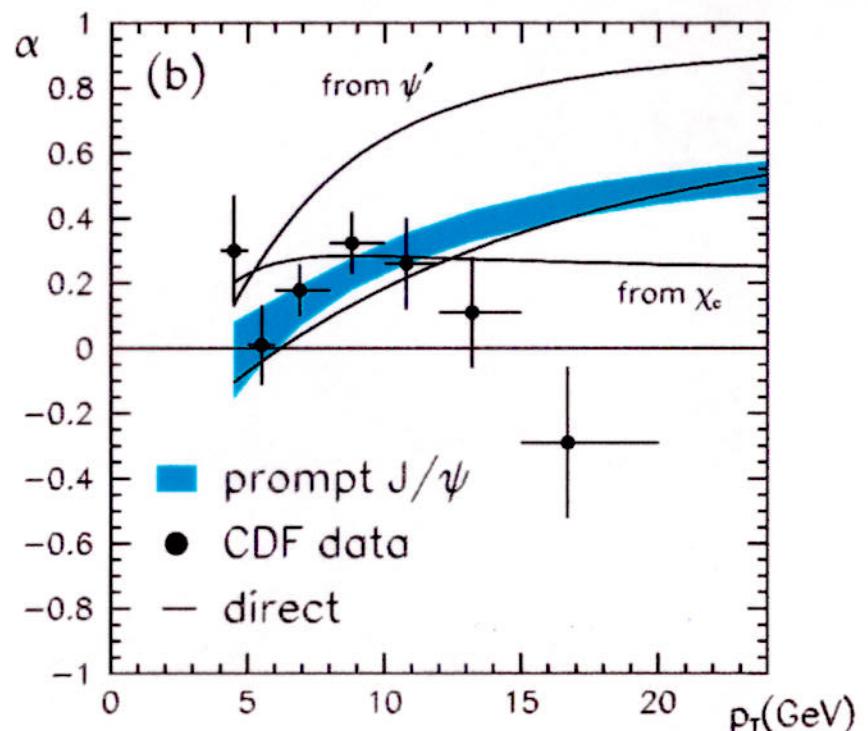
J/ψ from B decays
essentially unpolarized



CDF, PRL 85 (2000) 2886

Prompt J/ψ Polarization

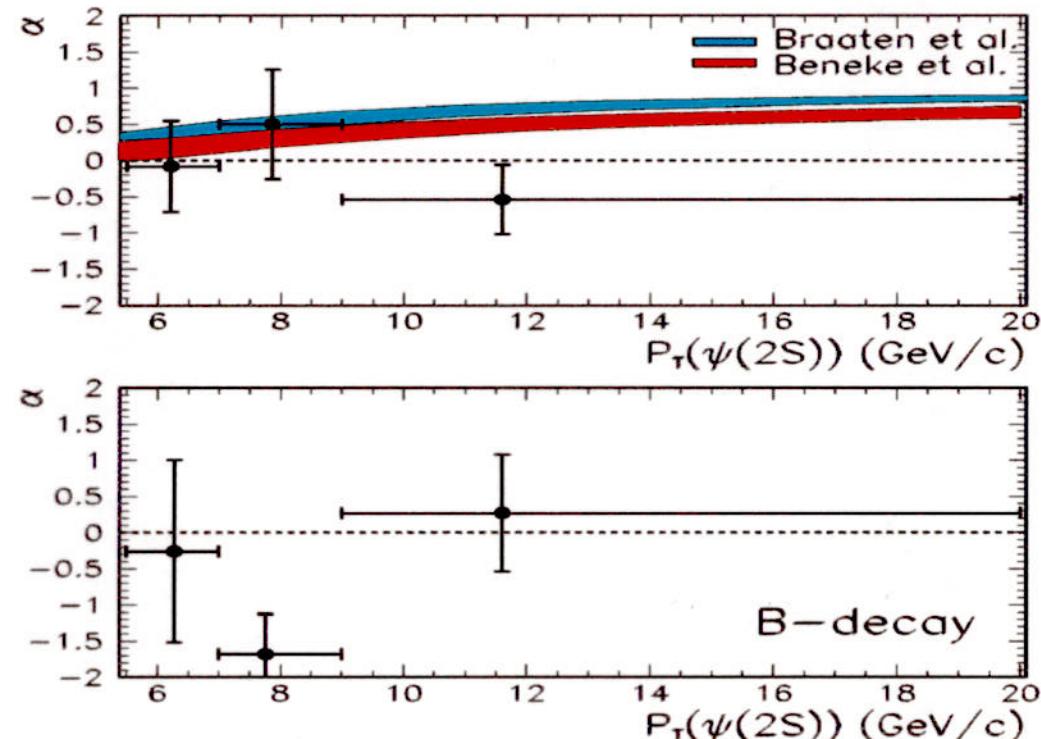
- Need to take into account $\psi(2S)$ and χ_c contributions
- Data do not show a trend towards transverse polarization at large p_T
- Phenomenological models give better description
 - ◆ E.g. **colour evaporation model**: mostly unpolarized J/ψ at large p_T



Braaten, Kniehl, Lee
PRD 62 (2000) 094005

$\psi(2S)$ Polarization

- Same procedure, but limited statistics
- Preferable to J/ψ since no **contamination** from indirect production
- Inconclusive

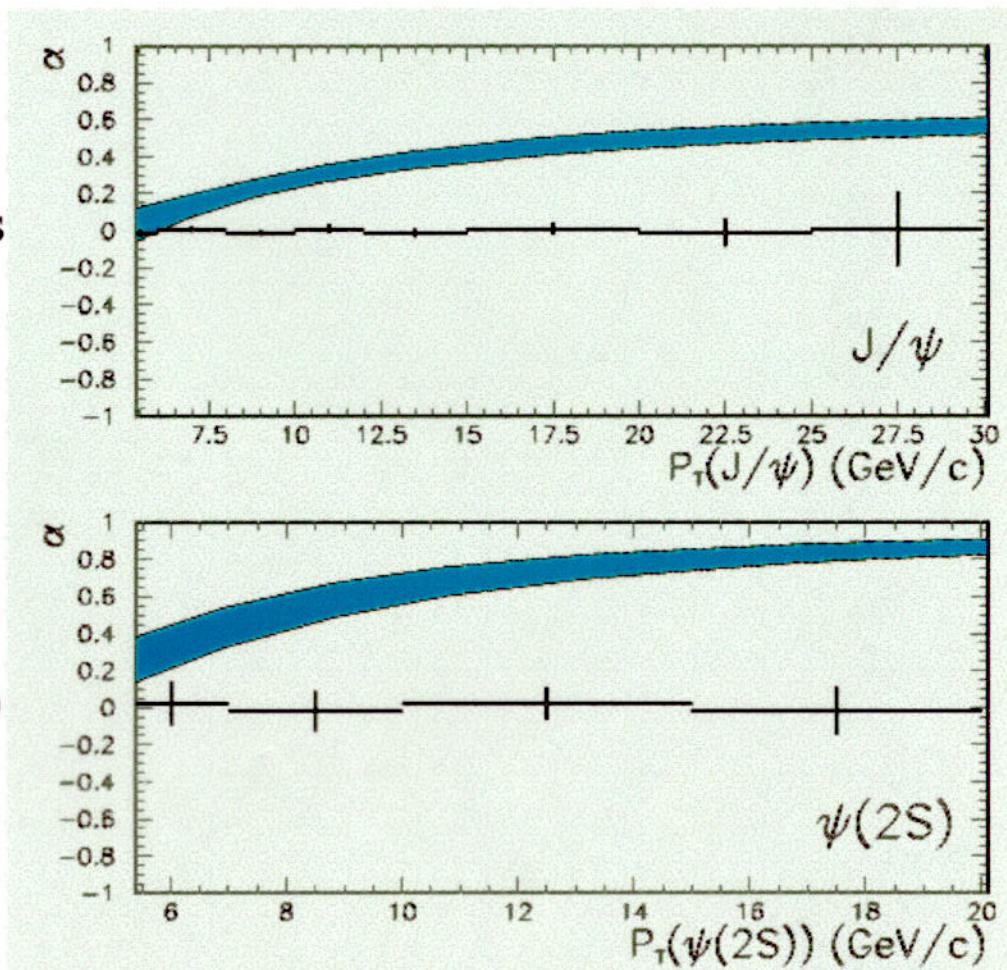


CDF, PRL 85 (2000) 2886

Polarization in Run II

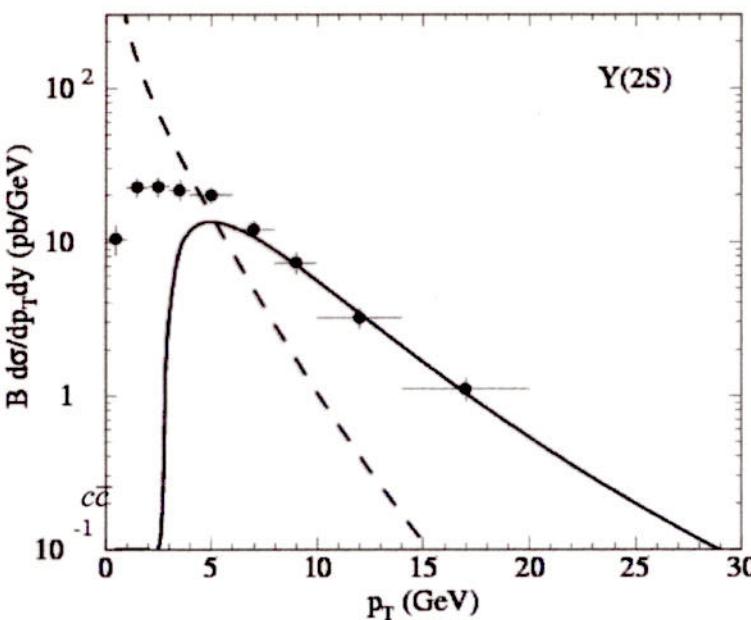
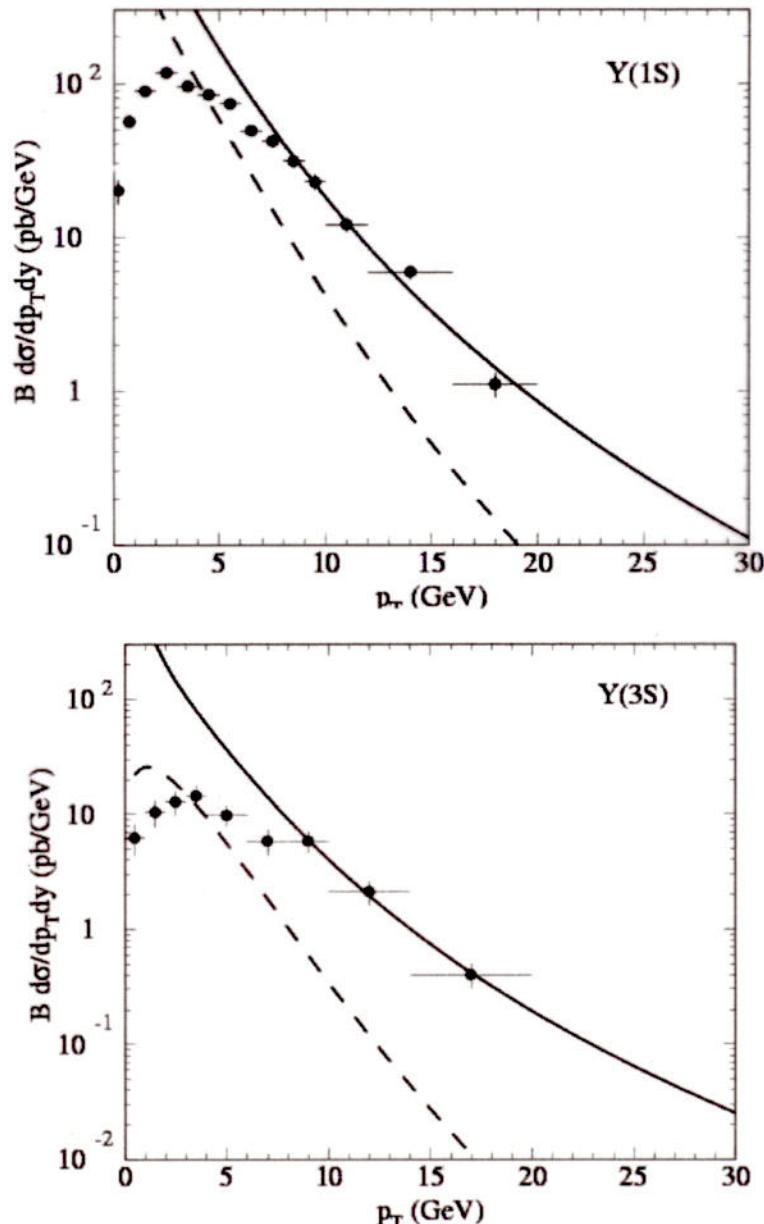
CDF study:

- Assume factor 50 in effective statistics
 - ◆ Integrated luminosity 2 fb^{-1}
 - ◆ Better SVX coverage (separate prompt/B)
- Lower dimuon trigger threshold (1.5GeV)
 - ◆ Able to measure down to $p_T(\text{J}/\psi)$ of ≈ 0
- Systematic uncertainties still small at larger p_T



Υ Cross Section at CDF

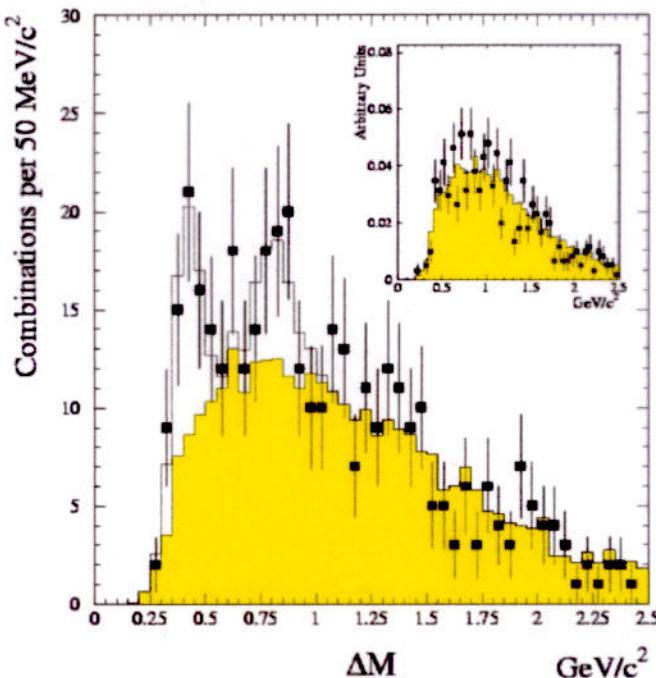
Run I:
PRL 88 (2002) 161802



- smaller discrepancy with CSM but similar to $c\bar{c}$ result
- NRQCD CS+CO terms able to fit data with $p_T > 8$ GeV/c

χ_b Feed-down to $\Upsilon(1S)$ at CDF

Run I:
PRL 84 (2000) 2094



- $\chi_b(1P, 2P) \rightarrow \Upsilon(1S)\gamma$
- $p_T(\Upsilon) > 8 \text{ GeV}/c$
- γ backgrounds: π^0, η, K_S decays

Direct $\Upsilon(1S)$: $(50.9 \pm 8.2 \pm 9.0)\%$

From $\chi_b(1P)$: $(27.1 \pm 6.9 \pm 4.4)\%$

From $\chi_b(2P)$: $(10.5 \pm 4.4 \pm 1.4)\%$

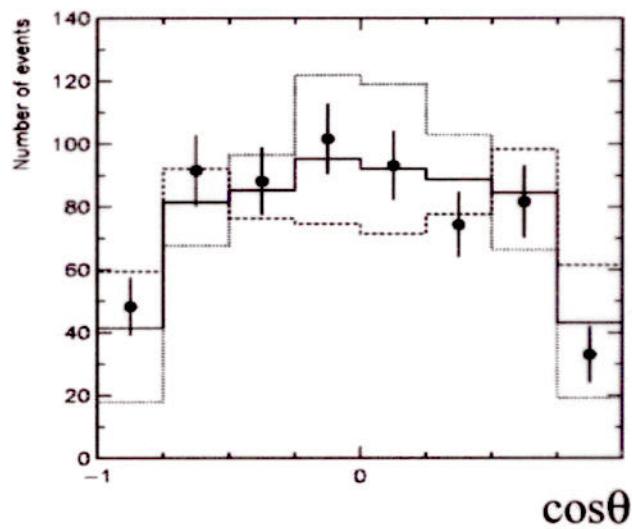
From $\Upsilon(2S)$: $(10.7^{+7.7}_{-4.8})\%$

From $\Upsilon(3S)$: $(0.8^{+0.6}_{-0.4})\%$

Input in theoretical calculations of
Bottomonium cross sections

Υ Polarization at CDF

Run I:
PRL 88 (2002)161802

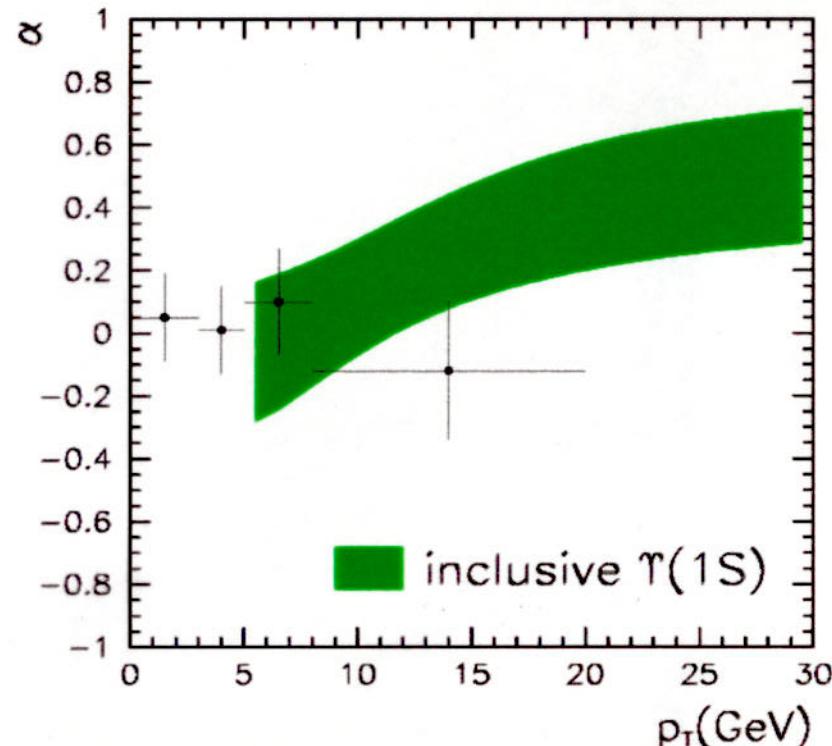


$|y| < 0.4$

$8 < p_T < 20 \text{ GeV}/c$

$$1 + \alpha \cos^2\theta$$

$$\alpha = 0.12 \pm 0.22$$



- similar to $c\bar{c} \rightarrow$ as yet inconclusive
- Insufficient data with $p_T > 20 \text{ GeV}/c$

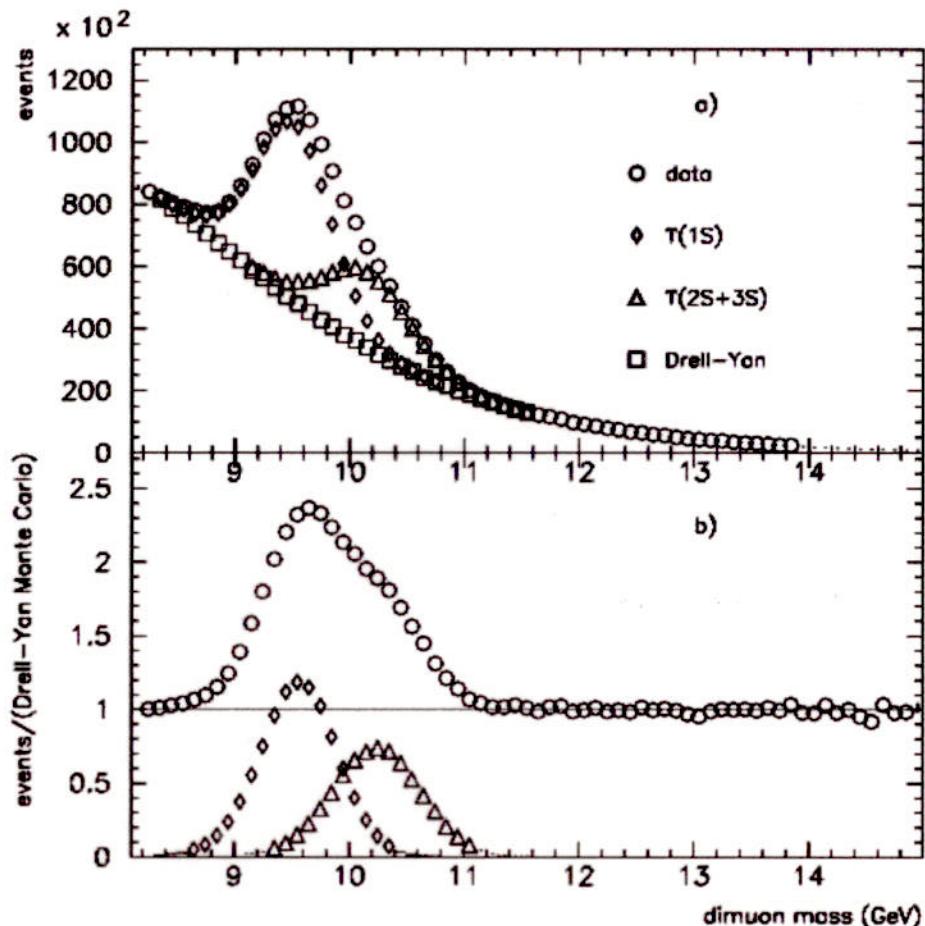
E866/Nusea, $\sqrt{s}=38.8$ GeV

$p + Cu \rightarrow \mu^+ \mu^- X$
(800 GeV proton beam)

$0 < x_F < 0.6$

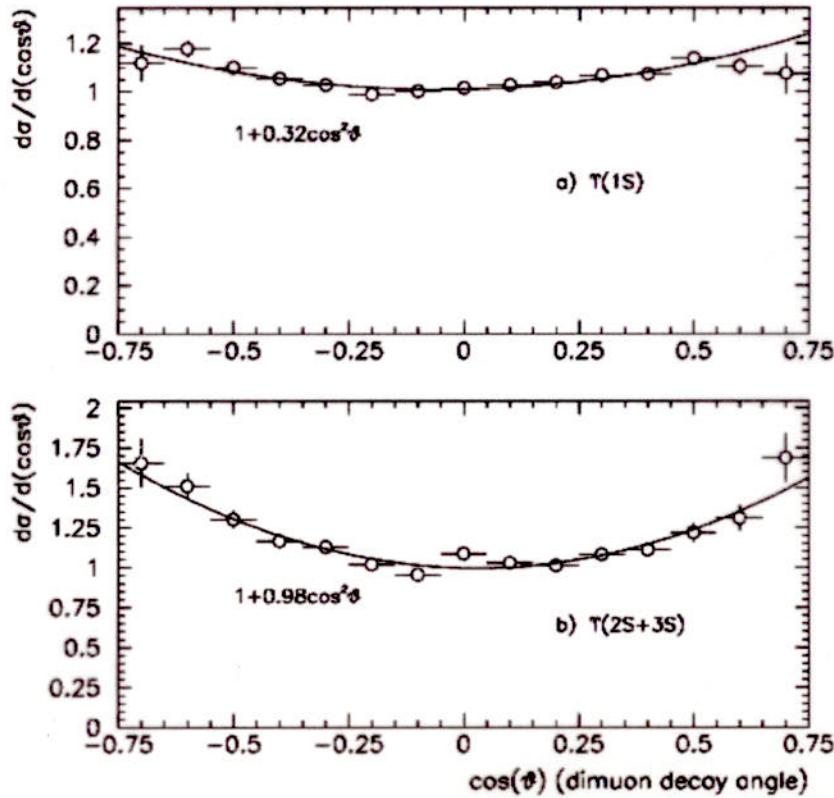
$p_T < 4$ GeV/c
(transverse to beam axis)

- $\Upsilon(2S)$ and $\Upsilon(3S)$ not distinguished
- Subtract Drell-Yan $\mu\mu$ continuum
(100% transverse polarization)
- sideband fit: $\alpha = 1.008 \pm 0.016 \pm 0.020$



E866/Nusea, Υ polarization

$\cos\theta$ distributions for $p_T > 1.8 \text{ GeV}/c$



- inclusive $\Upsilon(1S)$:

NRQCD: $\alpha = 0.28$ to 0.31 , avg over p_T, x_F

Observed: $\alpha = 0.07 \pm 0.04(\text{stat}) \pm 0.06(\text{sys})$

- inclusive $\Upsilon(2S) + \Upsilon(3S)$:

No explicit NRQCD prediction

Large observed transverse polarization, contrast with charmonium

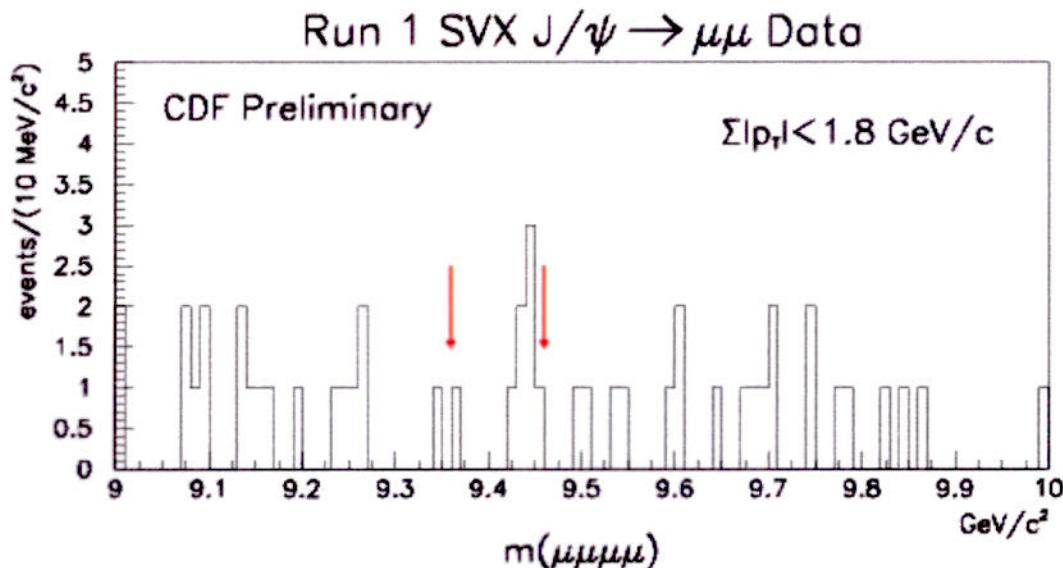
Search for η_b at CDF

$\eta_b \rightarrow J/\psi J/\psi$ reconstruction

Braaten, Fleming, Leibovich
PRD 63 (2001) 094006

Expected production rate:
 $\sigma(\eta_b) \sim (3\text{-}6) \times \sigma(\Upsilon(1S))$
 $B(\eta_b \rightarrow J/\psi J/\psi) \sim 7 \times 10^{-4\pm 1}$

100 pb⁻¹
Possibly seen in Run I?



Small cluster: 7 events, 1.8 events expected from background

CDF mass resolution $\sim 10 \text{ MeV}/c^2$
Search window $9.36 \text{ to } 9.46 \text{ GeV}/c^2$
Simple mass fit: $9445 \pm 6(\text{stat}) \text{ MeV}/c^2$
Probability of background fluctuation: 1.5% ($\sim 2.2 \sigma$)

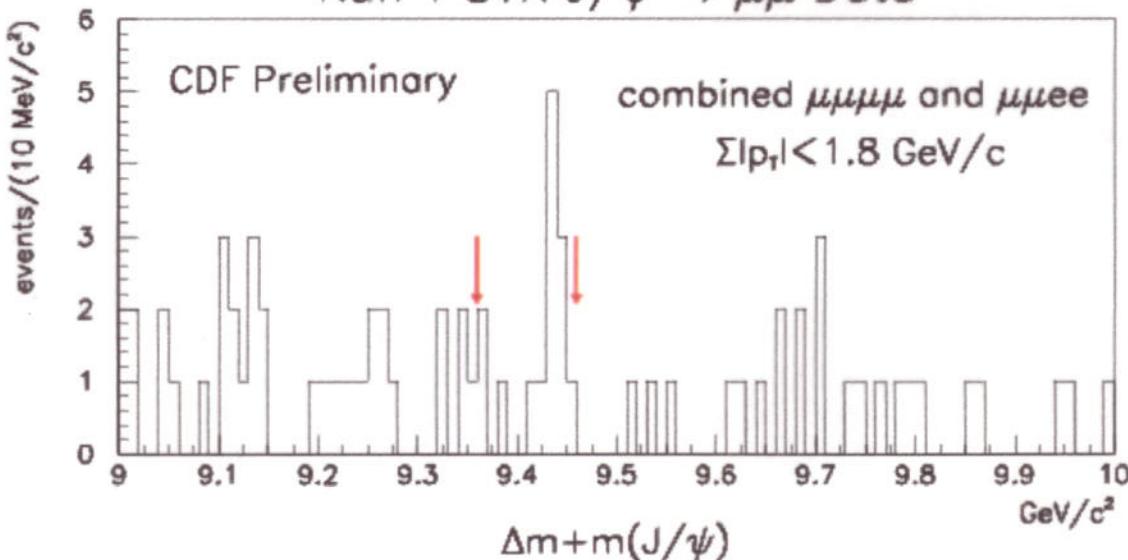
Search for η_b at CDF

$\eta_b \rightarrow J/\psi J/\psi$ reconstruction

Rate Limit:

$$\sigma \eta_b(|y| < 0.4) B(\eta_b \rightarrow J/\psi J/\psi) [B(J/\psi \rightarrow \mu\mu)]^2 < 18 \text{ pb}$$

Run 1 SVX $J/\psi \rightarrow \mu\mu$ Data



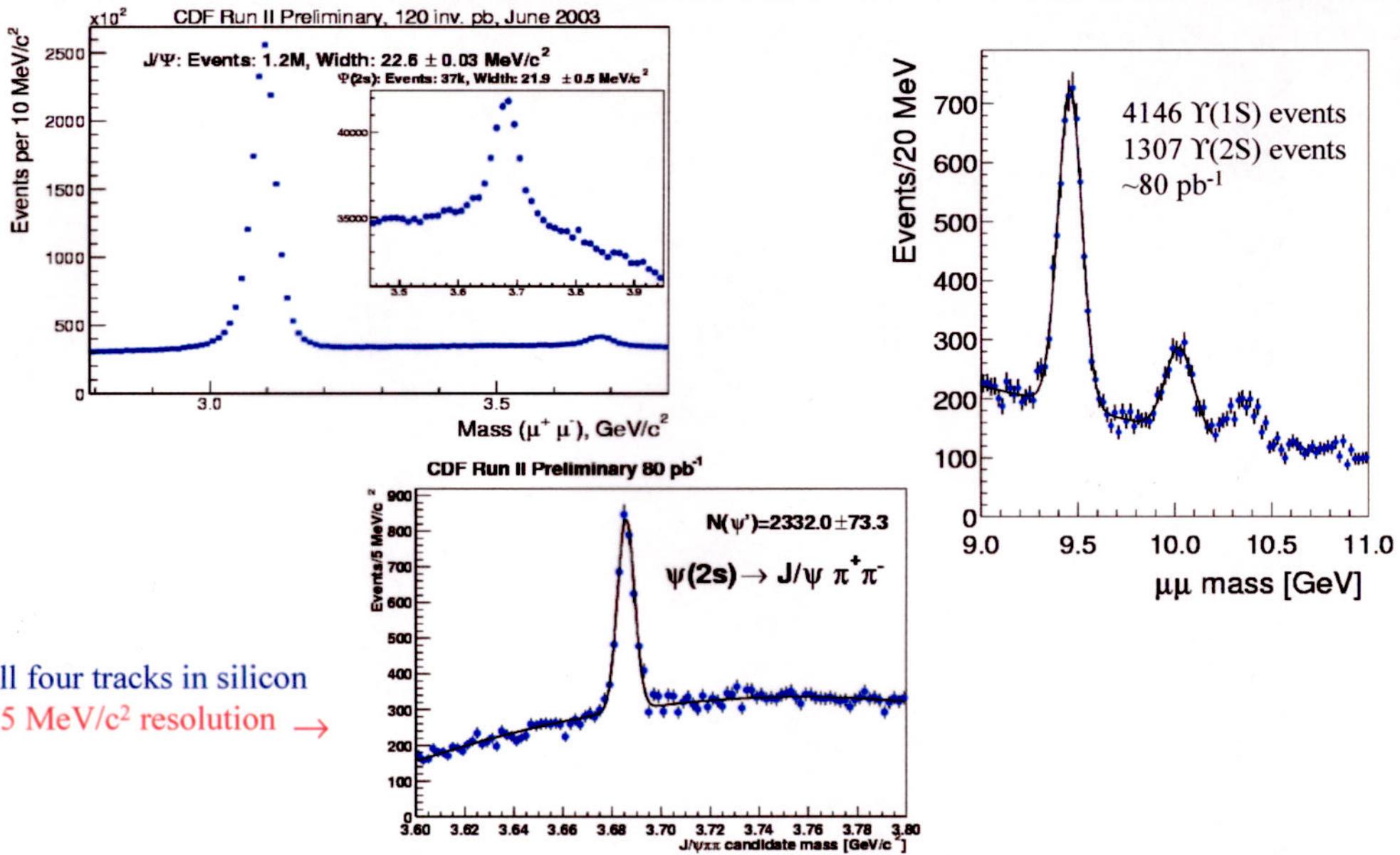
Central value 3.5 pb

Improves apparent significance
Supportive of signal hypothesis
Need more data for confirmation

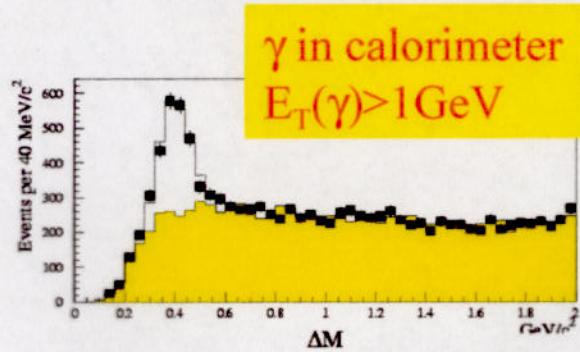
Prospects for Run II

- $\int L dt \approx 1.4 \text{ fb}^{-1}$ by end of FY05, $\int L dt \approx 9 \text{ fb}^{-1}$ by end of FY09
 - ◆ Run II is well underway, data samples about 30% bigger than Run I now
- Will get many J/ψ 's and $\psi(2S)$ for free, but
 - ◆ Is the charm system massive enough?
 - ◆ For J/ψ , will always have feed-down to J/ψ final states
- For most measurements, there are now two experiments
- Also better muon and silicon coverage, improved trigger capabilities, decays into e^+e^- (?)
- There will be other possible measurements that can shed light on the colour octet issue
 - ◆ $h_c, \chi_c, \Upsilon, \chi_b$... production cross sections
 - ◆ Associated jets in direct production

Run II - CDF

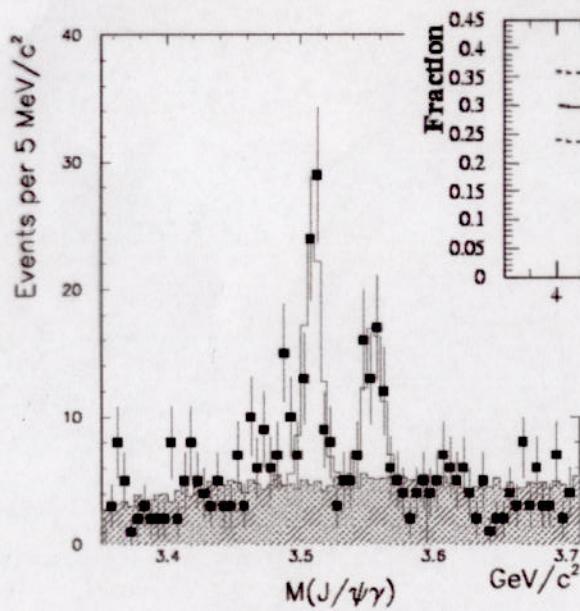


Run II – (CDF/D0 on χ_c)

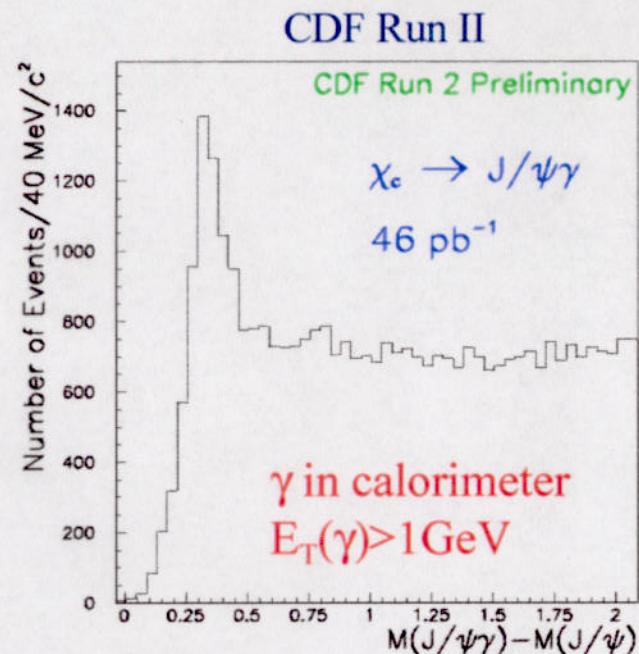


CDF - Run I

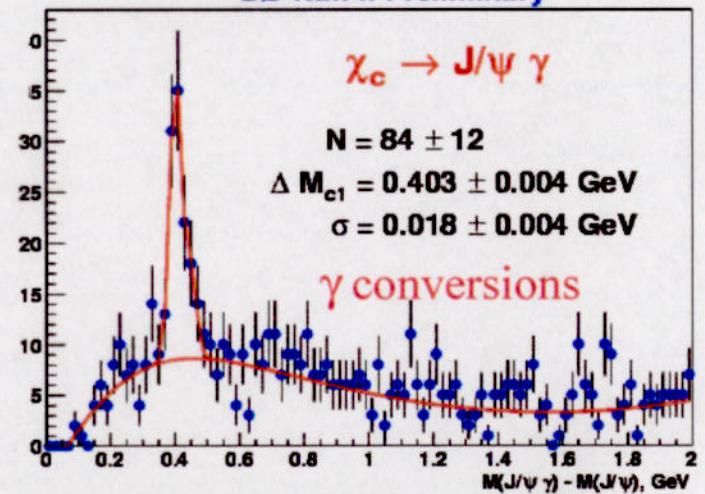
PRL 79 (1997) 578
 PRL 86 (2001) 4472



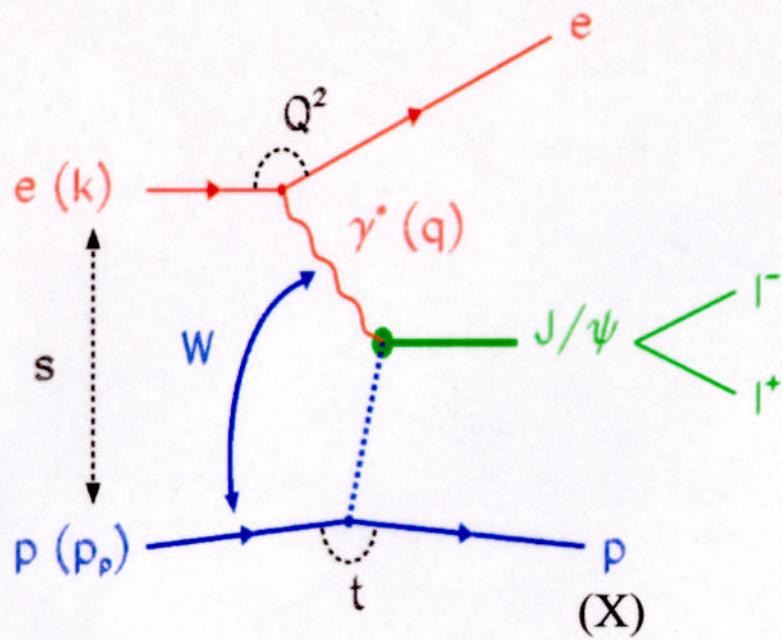
γ conversions



DØ Run II Preliminary



Quarkonia at HERA



$$Q^2 := -q^2$$

$$W^2 := (p_p + q)^2 \approx Q^2 / x$$

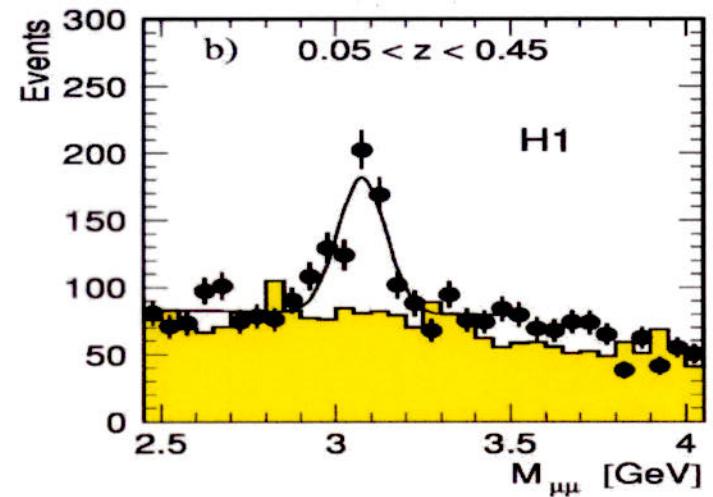
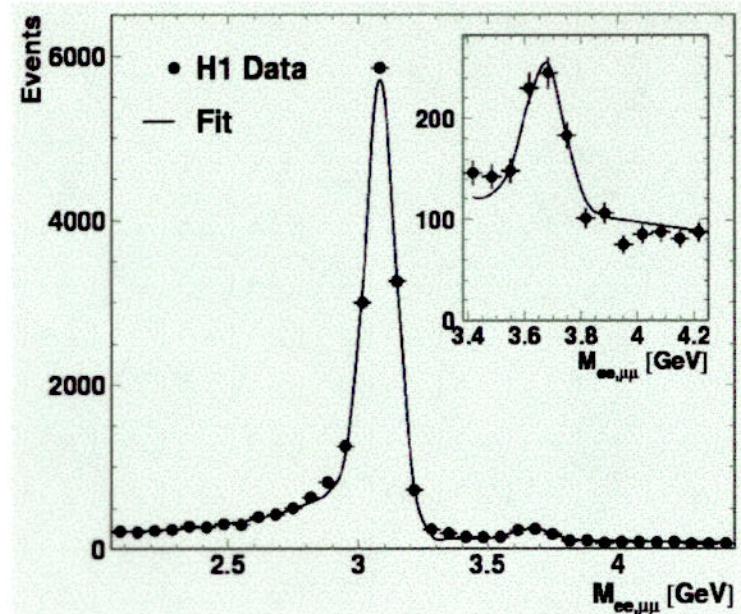
$$Q^2 := xys$$

- DIS
 - ◆ $1 < Q^2 < 100 \text{ GeV}^2$
- Tagged/untagged photoproduction
 - ◆ Scattered e not seen in main detector
 - ◆ Median $Q^2 \cong 10^{-4} \text{ GeV}^2$
- Decays into e^+e^- and $\mu^+\mu^-$
- Central tracking ($|\eta| < 1.8$)
 - ◆ $30 < W < 180 \text{ GeV}$
 - ◆ In addition, dedicated analyses with specific statistical and systematic limitations (forward muon spectrometer, backward calorimetry, ...)

J/ ψ at HERA

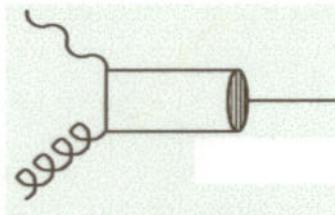
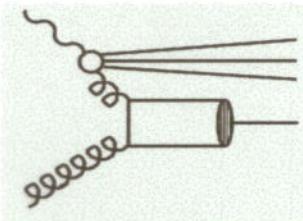
$$z = \frac{P_p \cdot P_\psi}{P_p \cdot P_\gamma} = \frac{E_\psi}{E_\gamma} \quad \text{in p rest frame}$$

- Order of magnitude comparable
 - ◆ “Elastic” $z \approx 1 (M_X = m_p)$
 - ◆ p diffractive dissociation $z \approx 1 (\sigma \propto 1/M_X^2)$
 - ◆ “Inelastic” $z < 1$
- At small z contributions from
 - ◆ Resolved photon
 - ◆ B production
- Background increases with decreasing z



HERA Production Mechanisms

Inelastic



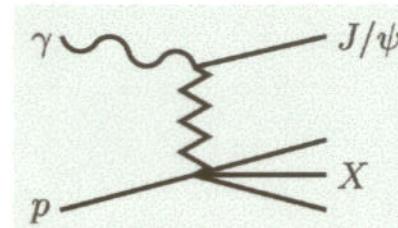
"resolved" (gg-fusion) direct (γg -fusion)
($z < 0.3$)

J/ψ from $\psi(2S)$ decays ($\psi(2S) \rightarrow J/\psi\pi\pi$ and others)
(not subtracted, measured, $\sim 15\%$)

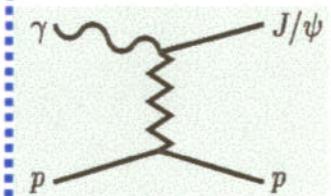
J/ψ from χ_c decays (not subtracted)
(1% of inelastic, up to 7% at lowest z)

J/ψ from B decays (not subtracted)
(5% of inelastic, up to 25% at lowest z)

p-dissociation



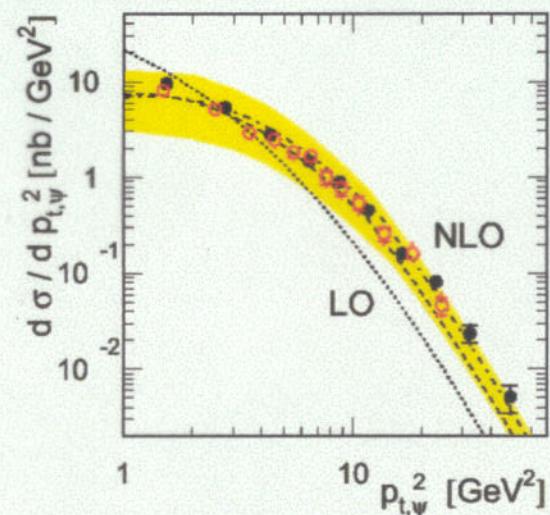
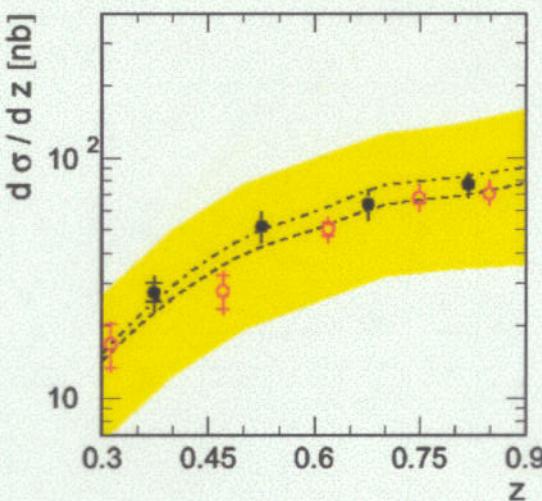
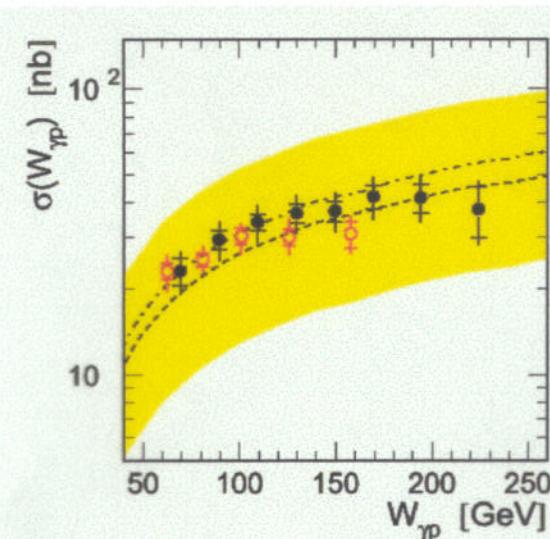
Elastic



Cut on z , (fwd.) energy,
add'l tracks, ...

"Forward tagging"

J/ ψ Photoproduction: CSM



- H1
- CSM NLO
- - - CSM LO
- ZEUS (scaled)

Errorbands:
 $1.3 \leq m_c \leq 1.5 \text{ GeV}$
 $0.1175 \leq \alpha_s(M_Z) \leq 0.1225$

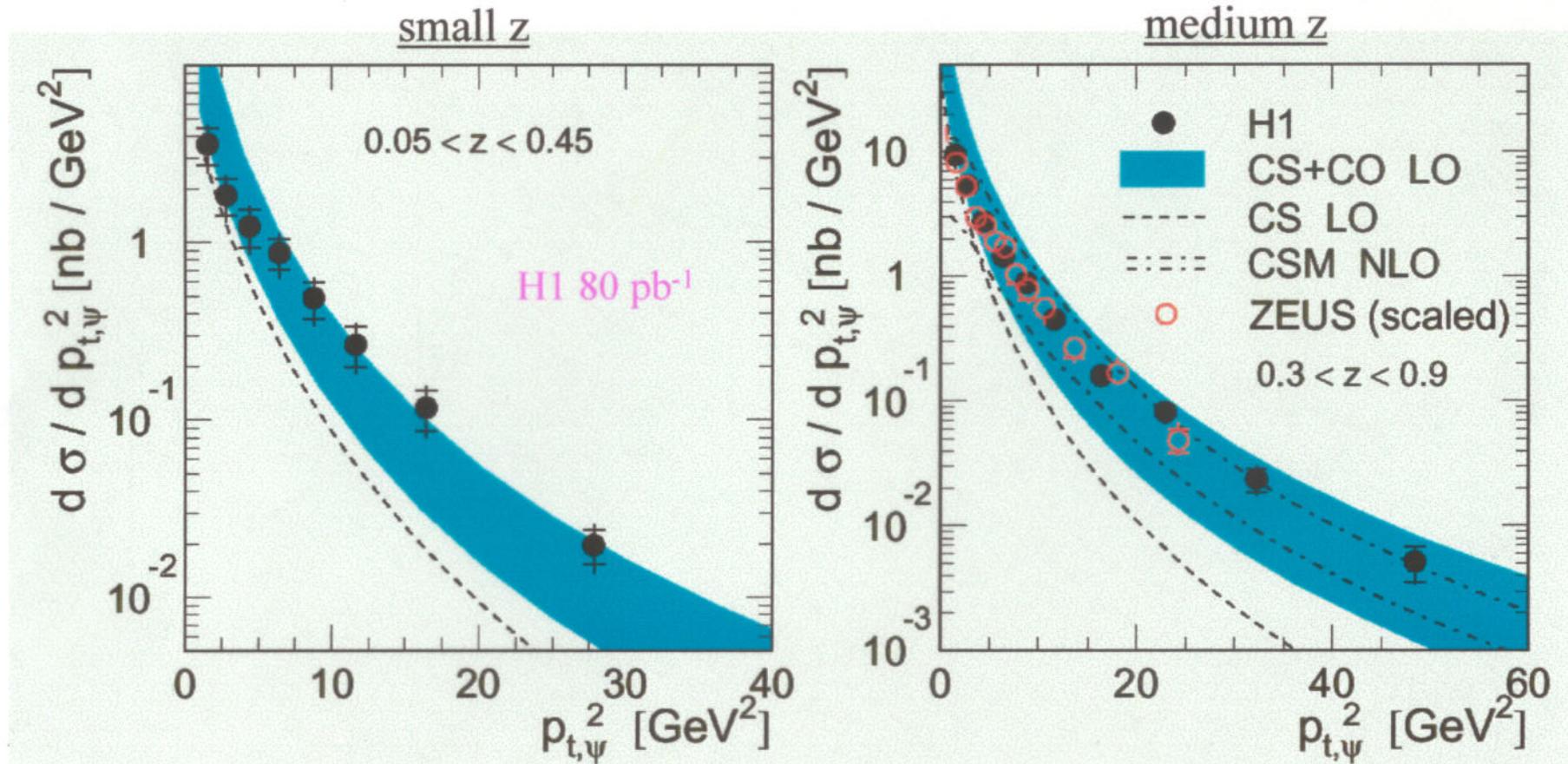
H1: EJC25 (2002) 25

Zeus: EJC27 (2002) 173

Colour Singlet Model: NLO
calculation of direct photon gluon
fusion process (M.Krämer)

LO: too steep
NLO: good agreement

J/ψ Photoproduction: NRQCD



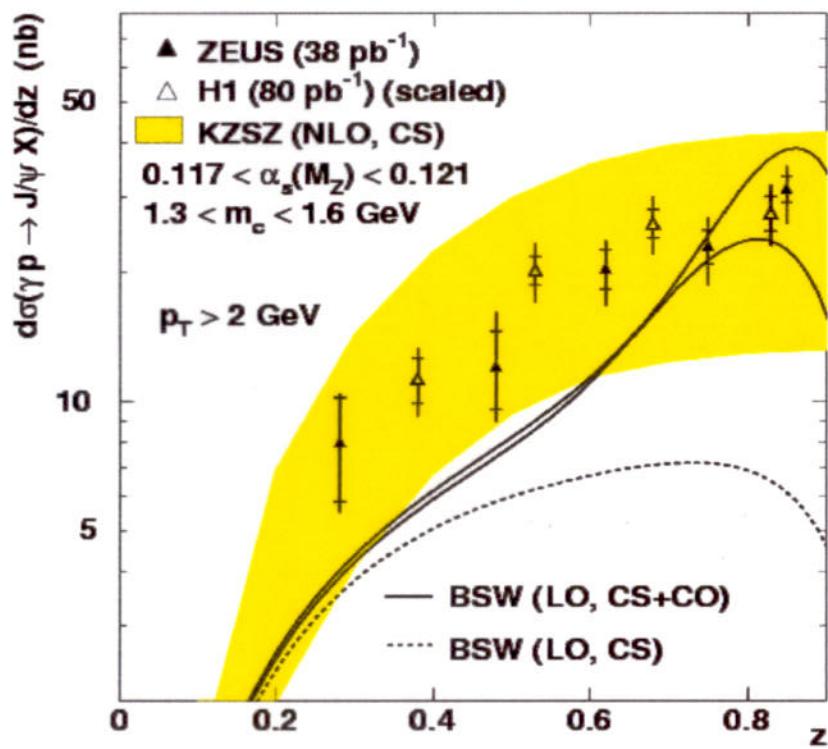
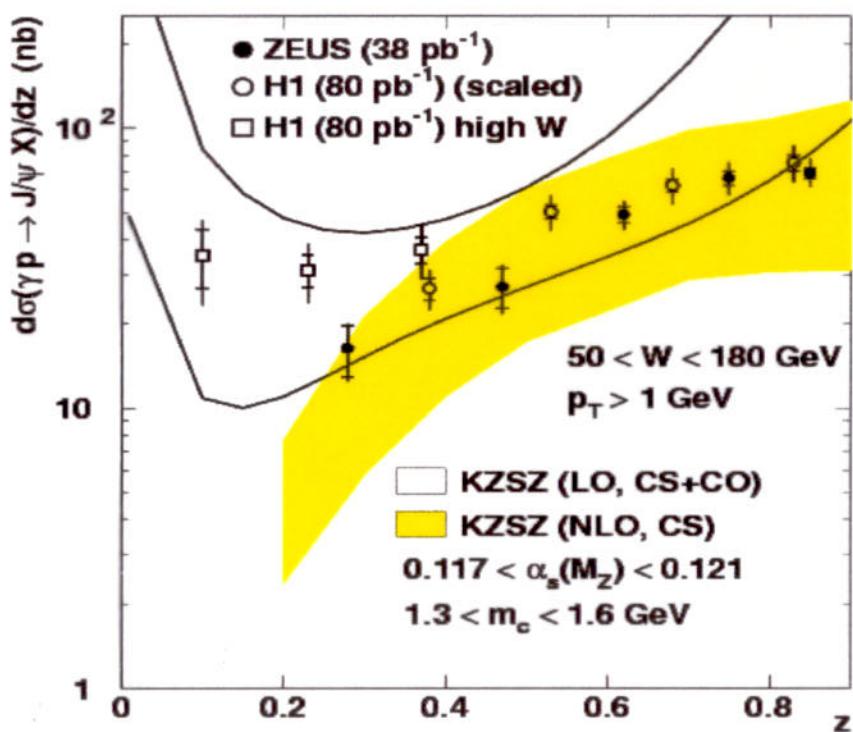
- p_T spectra similar at low and medium z
- NRQCD (including CS and CO): softer than data
 - ◆ Contributions from B decays in data?

H1: EJ C25 (2002) 25
Zeus: EJ C27 (2002) 173

J/ ψ Photoproduction: inelasticity

EJ C25 (2002) 25
EJ C27 (2002) 173

CO long-distance ME taken from fit to CDF data

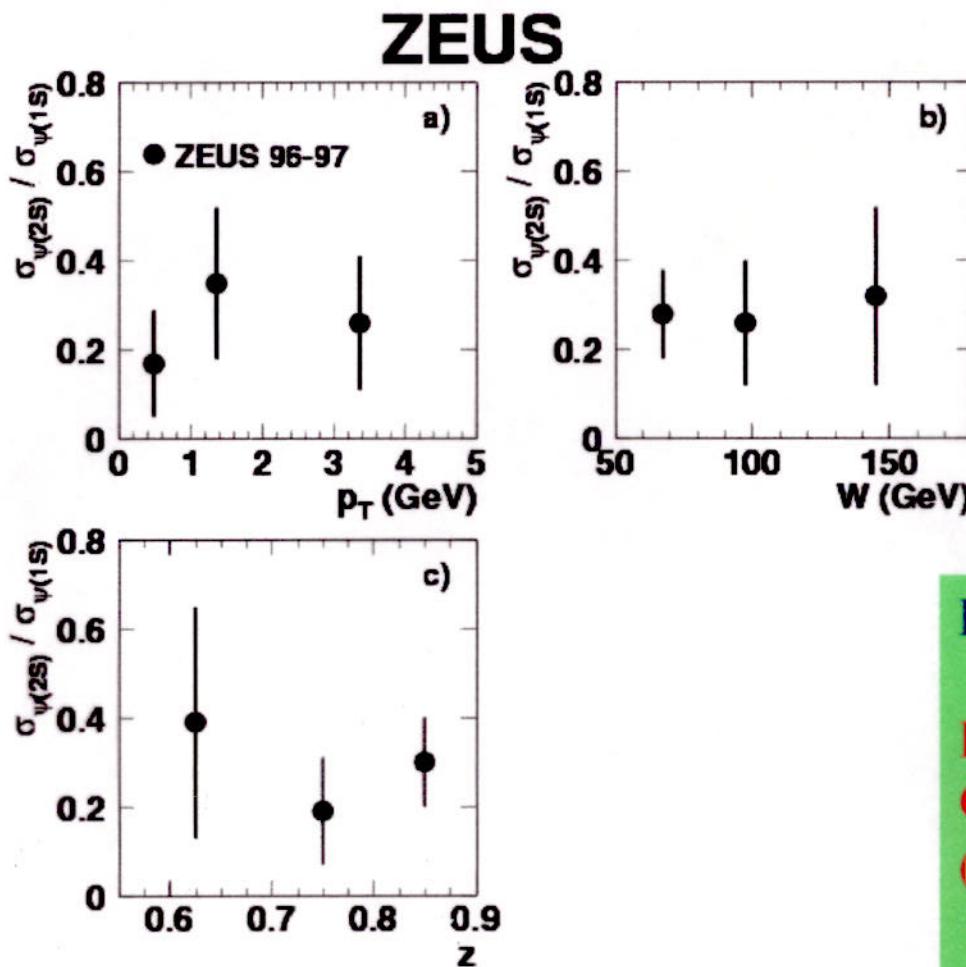


NLO CSM agrees with data; Theoretical uncertainties do not allow strong conclusions on CO

Left: NRQCD describes shapes (large LDME uncertainties)

Right: Damping at high z for BSW (LO, CS+CO) \Rightarrow better agreement

Photoproduction: $\sigma_{\psi(2S)} / \sigma_{\psi(1S)}$



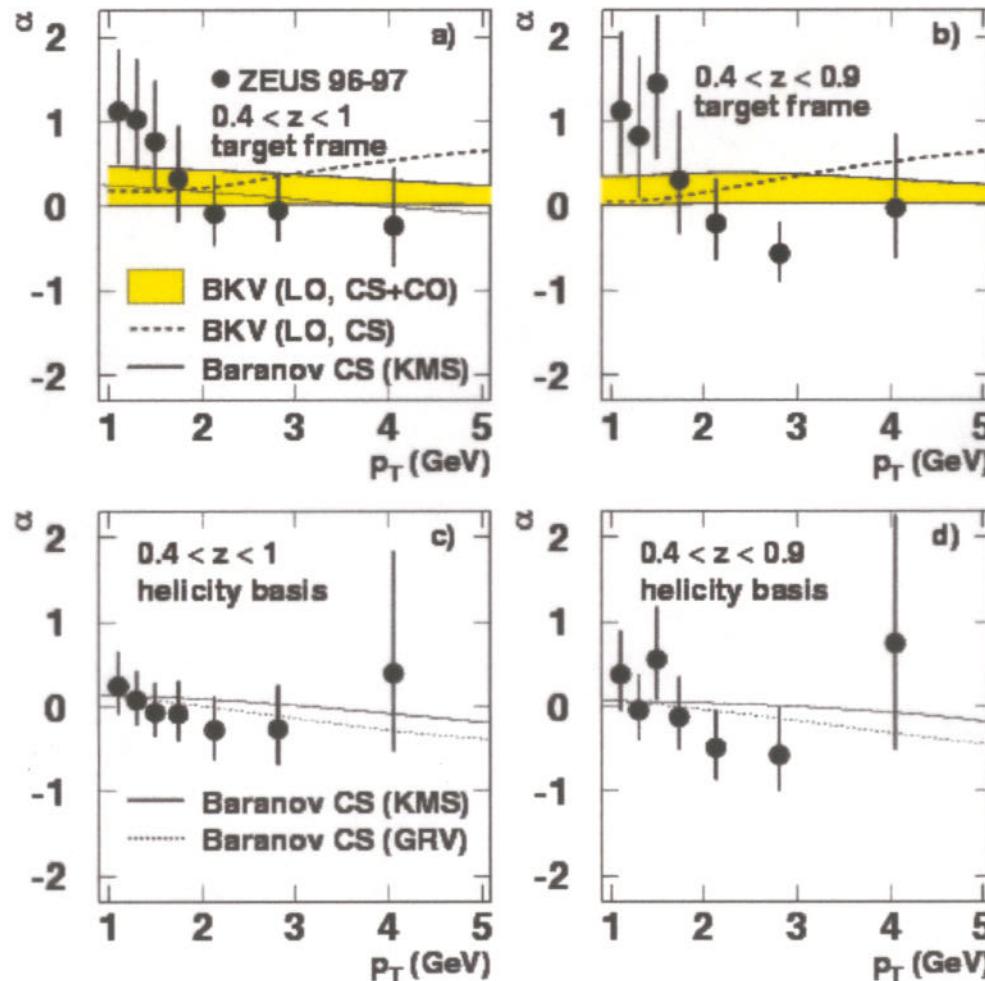
$$\sigma_{\psi(2S)} / \sigma_{\psi(1S)} = 0.33 \pm 0.10^{+0.01}_{-0.02}$$

Flat, consistent with 0.24 from KZSZ (LO,CS)

Estimate of J/ ψ fraction coming from $\psi(2S)$
Cascade decays consistent with expectations
(15%)

Photoproduction: helicity

ZEUS



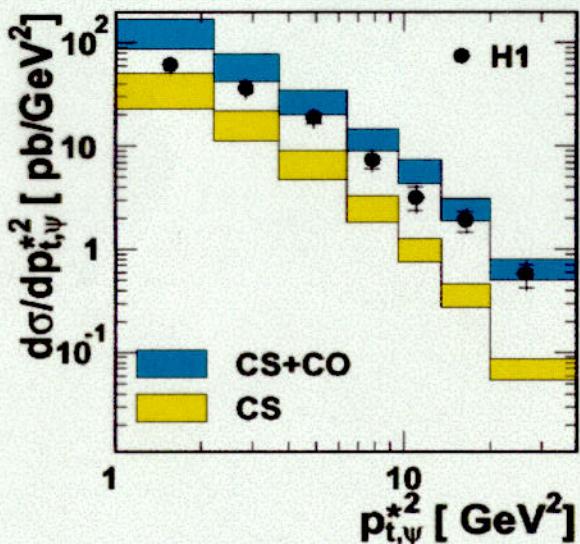
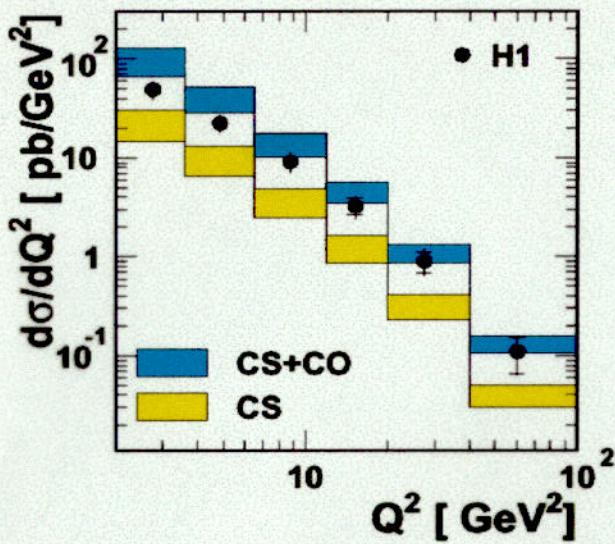
$$dN/d\cos\theta^* \propto 1 + \alpha \cos^2\theta^*$$

BKV – collinear calculations

Baranov – k_t -factorization

Statistics is not yet sufficient to discriminate between models

H1 - J/ψ Electroproduction



Data: $2 < Q^2 < 100 \text{ GeV}^2$

EJ C25 (2002) 41

$0.3 < z < 0.9$

$50 < W < 225 \text{ GeV}$

$p_T^* > 1 \text{ GeV}$

$\int L dt = 77 \text{ pb}^{-1}$

Theory: LO Colour Singlet Model

LO NRQCD (CS+CO)

(B.A.Kniehl, L.Zwirner, NP B621(2002) 337)

CS alone: normalization low, too steep in p_T

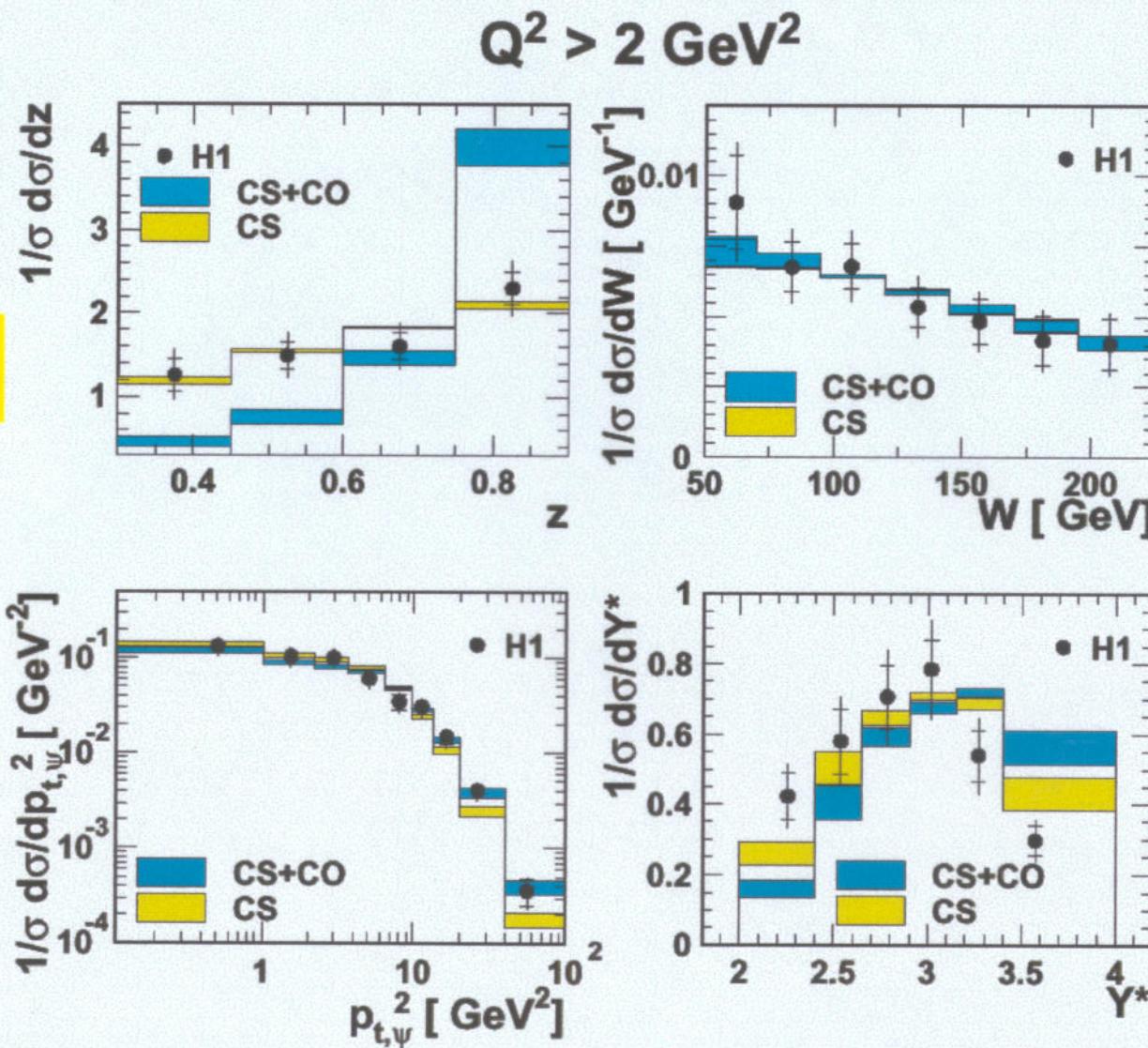
NRQCD (CS+CO): too high at low Q^2 , p_T
better at high Q^2 , p_T

Need: **NLO calculations**

More data at larger Q^2 , p_T

H1 - J/ψ Electroproduction

Large shape discrepancy

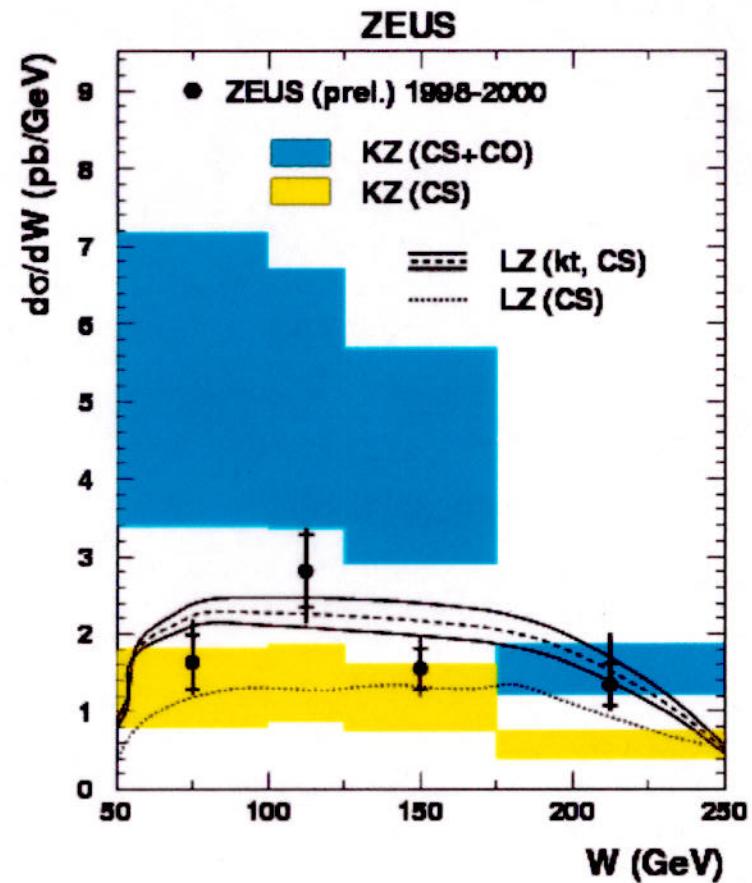
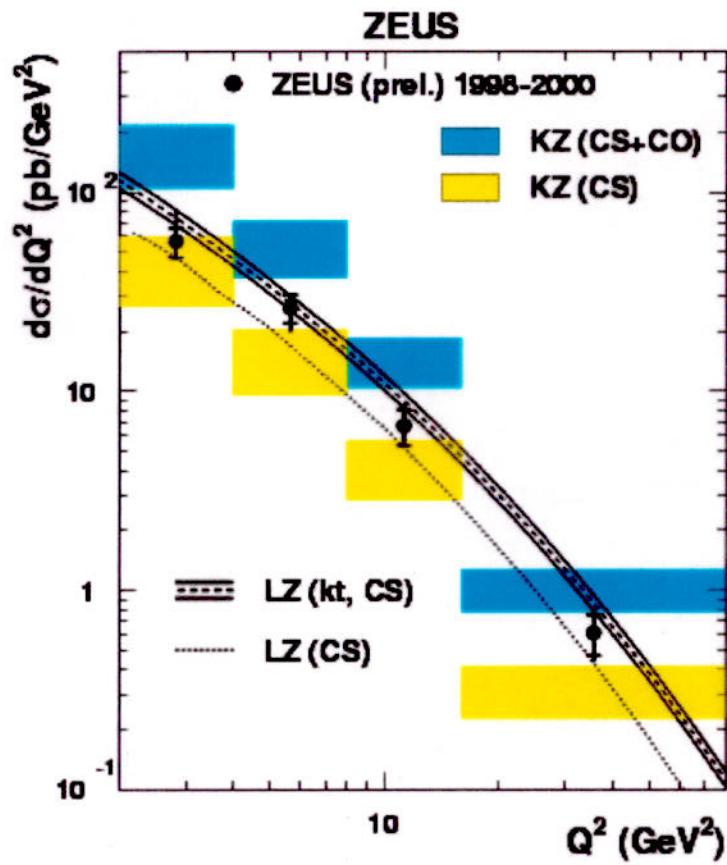


Note: Theory normalized to data

EJ C25 (2002) 41

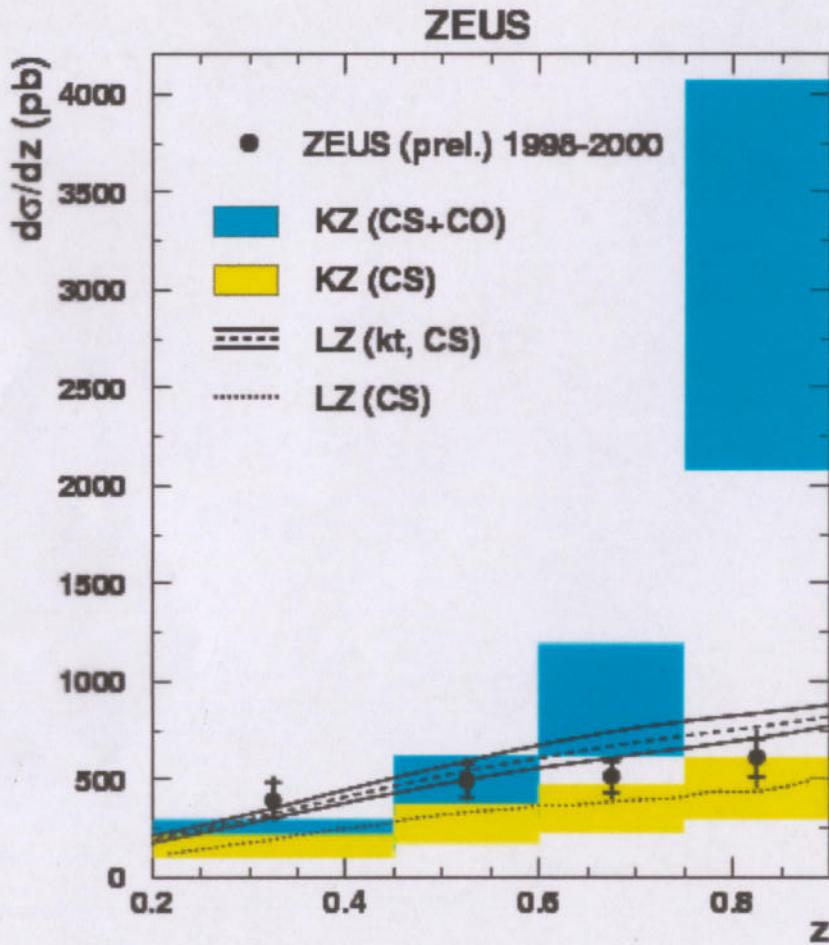
Rapidity in γp
CMS

Zeus - J/ ψ Electroproduction: Q^2 and W



- KZ(CS) and LZ(CS): lower but consistent with data
- KZ(CS+CO): mostly overshoots data
- LZ(kt, CS): agrees with data

Zeus - J/ψ Electroproduction: inelasticity



- KZ(CS+CO): too high at large z values (high- z resummation needed?)
- CS predictions are consistent with data

HERA photo/electro production summary

➤ Photoproduction

- NLO corrections enable one to describe high production of J/ψ within CSM
- Theoretical uncertainties are large: CO contributions cannot be excluded

➤ Electroproduction

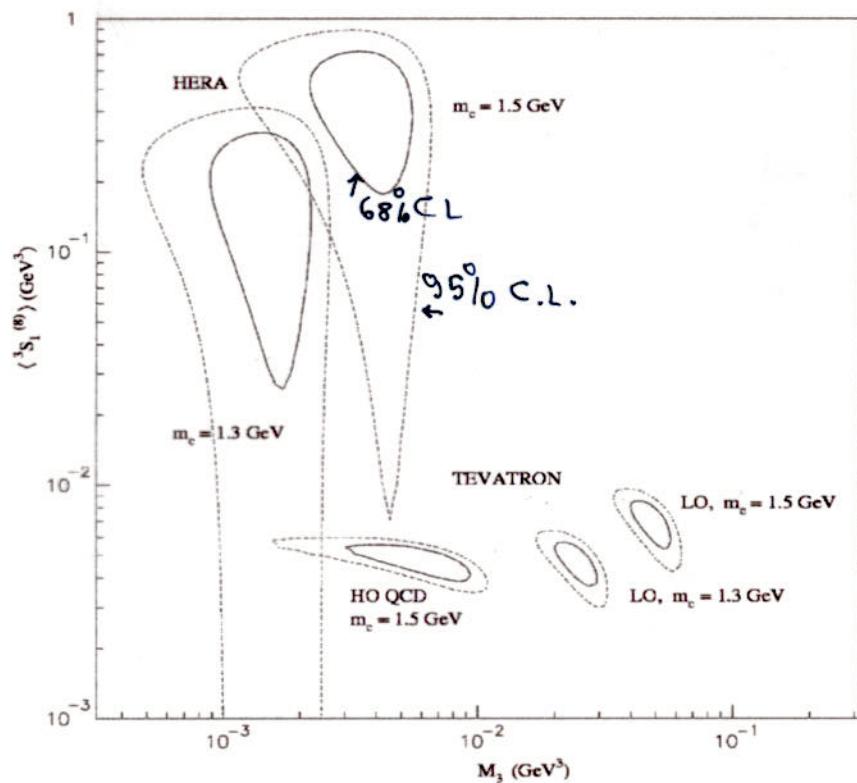
- LO CS: below but consistent with data, except high p_T range (NLO corrections?)
- NRQCD (CS+CO): too high at large z and small p_T^* values
- k_t -factorization (CS): agrees with data except at high p_T^* (too low) and in photon direction (too high)

HERA Prospects

- “HERA I” running period ended in September 2000
 - ◆ Another $> 50 \text{ pb}^{-1}$ per experiment collected in 2000, giving a total of $> 100 \text{ pb}^{-1}$
- Many analyses make use of the full data sets
- After the HERA upgrade:
 - ◆ $\int L dt \sim 100 \text{ pb}^{-1}$ per experiment expected by summer 2004
 - ◆ Polarized e^\pm beams
- Various detector upgrades
 - ◆ ZEUS Silicon
 - ◆ New fast track trigger for H1
 - ◆ ...
- High Q^2/p_T will greatly benefit from increase in luminosity

HERA vs. Tevatron ME

- Only use theoretically safe regime: $p_T^2, Q^2 > 4 \text{ GeV}^2, M_X > 10 \text{ GeV}$
 - ◆ Statistics limited in 1999
- Consistent description difficult
- Repeat including recent data?
- Common fit?



$$\langle {}^1S_0(8) \rangle + \frac{3}{m_c^2} \langle {}^3P_J(8) \rangle$$

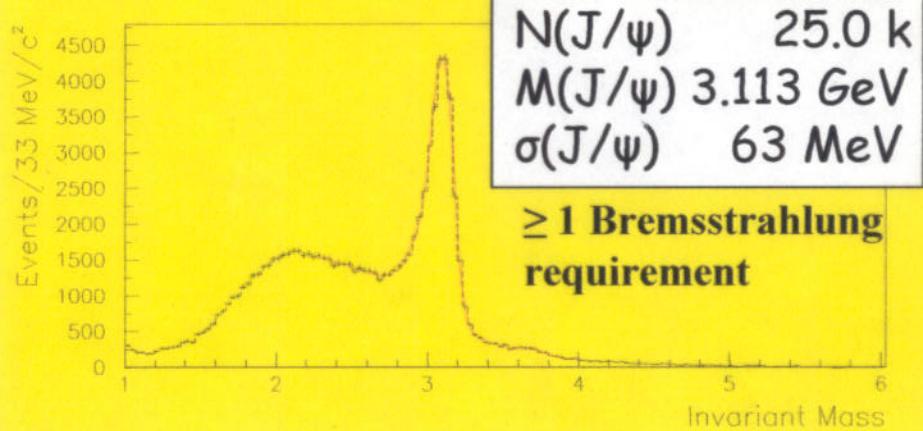
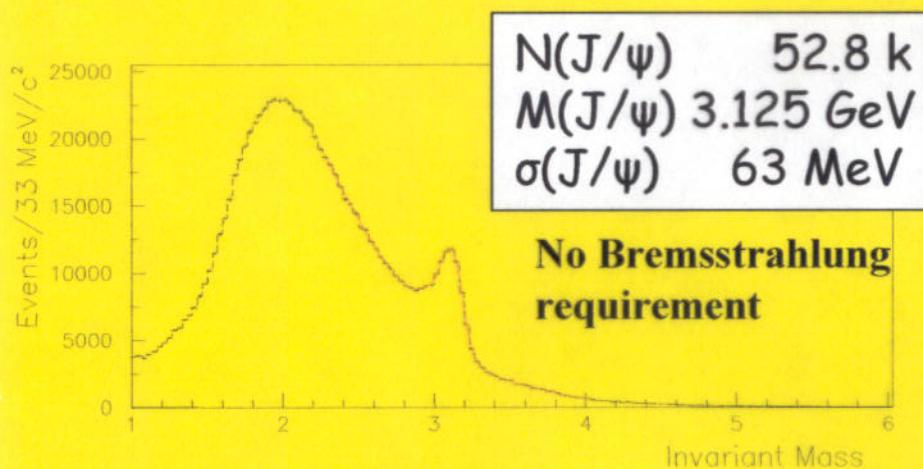
J.K.Mizukoshi,
hep-ph/9911384

HERA-B

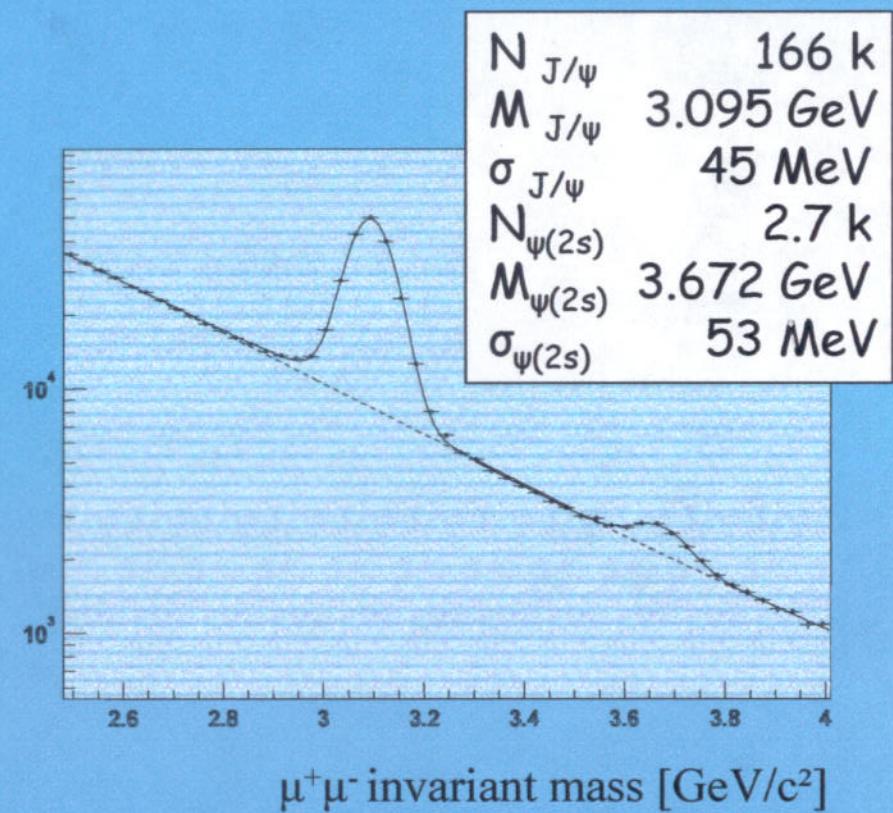
- HERA-B detector & trigger in good shape
 - ◆ Data taking : 30.October 2002 - 3.March 2003
 - ◆ 1200-1400 J/ ψ per hour, 70% of available beam time used
 - ◆ ~ 300,000 triggered J/ ψ ($e^+e^-/\mu^+\mu^-$)
 - ◆ ~ $210 \cdot 10^6$ Minimum bias events
- Analysis of 2002/03 data in progress

J/ ψ - Statistics

$J/\psi \rightarrow e^+e^-$: 40 % of statistics



$J/\psi \rightarrow \mu^+\mu^-$: full statistics



X

Detached J/ ψ Analysis

$J/\psi \rightarrow e^+e^-$

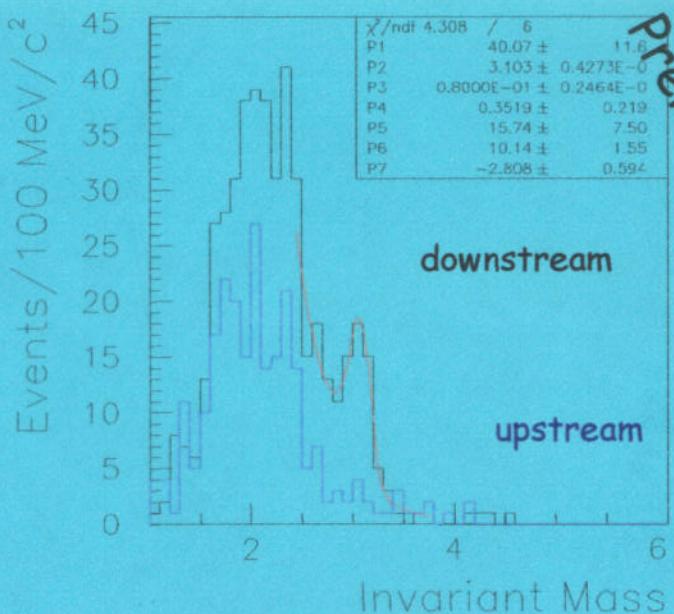
(40 % of statistics)

2000 :
 $n_B = 8.6^{+3.9}_{-3.2}$

$\Delta z / \sigma_z > 10$
 impact par. cut

No bremsstrahlung
 requirement

$J/\psi = 40 \pm 12$



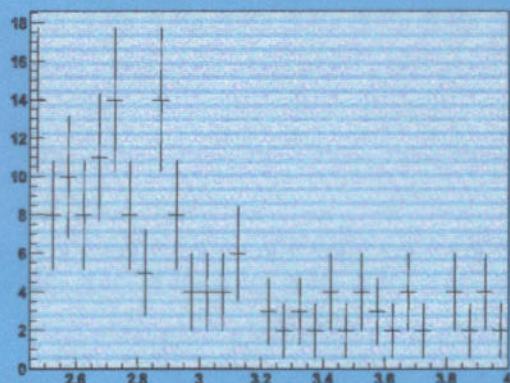
$J/\psi \rightarrow \mu^+\mu^-$

(60 % of statistics)

2000 :
 $n_B = 1.9^{+2.2}_{-1.5}$

$\Delta z < -0.5$ cm

Impact par. cut



No upstream J/ψ

$\Delta z > 0.5$ cm

Entries	740
χ^2/ndf	22.73/26
N(J/ψ)	40.35 ± 11.22
M(J/ψ)	3.087 ± 0.022
$\sigma(J/\psi)$	0.0696 ± 0.0154

$J/\psi = 40 \pm 11$

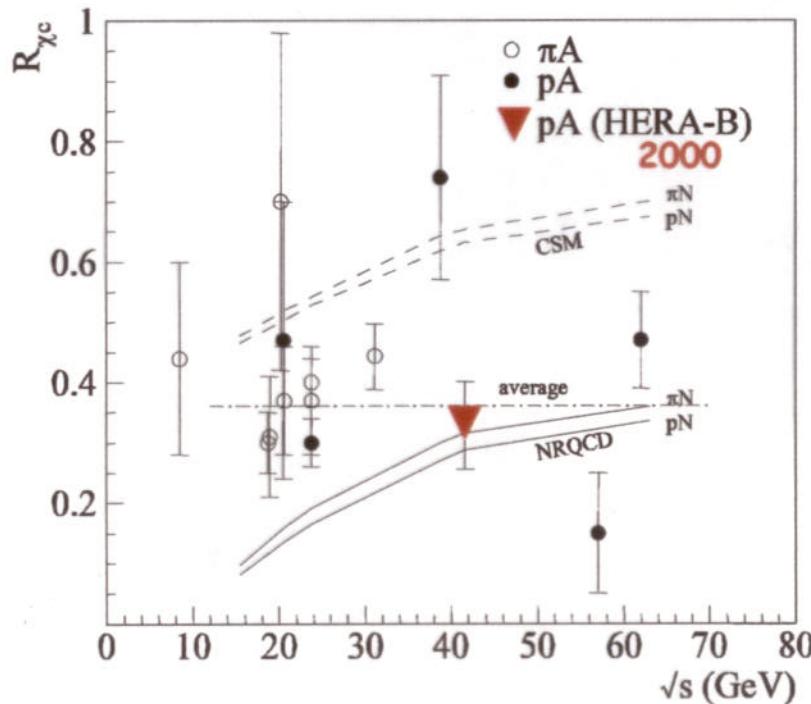
Preliminary

Preliminary

Charmonium Production : χ_c

Fraction of J/ψ produced via χ_c

$$R_{\chi_c} = \frac{\sum \sigma(\chi_{ci}) \text{Br}(\chi_{ci} \rightarrow J/\psi \gamma)}{\sigma(J/\psi)_{\text{tot}}}$$



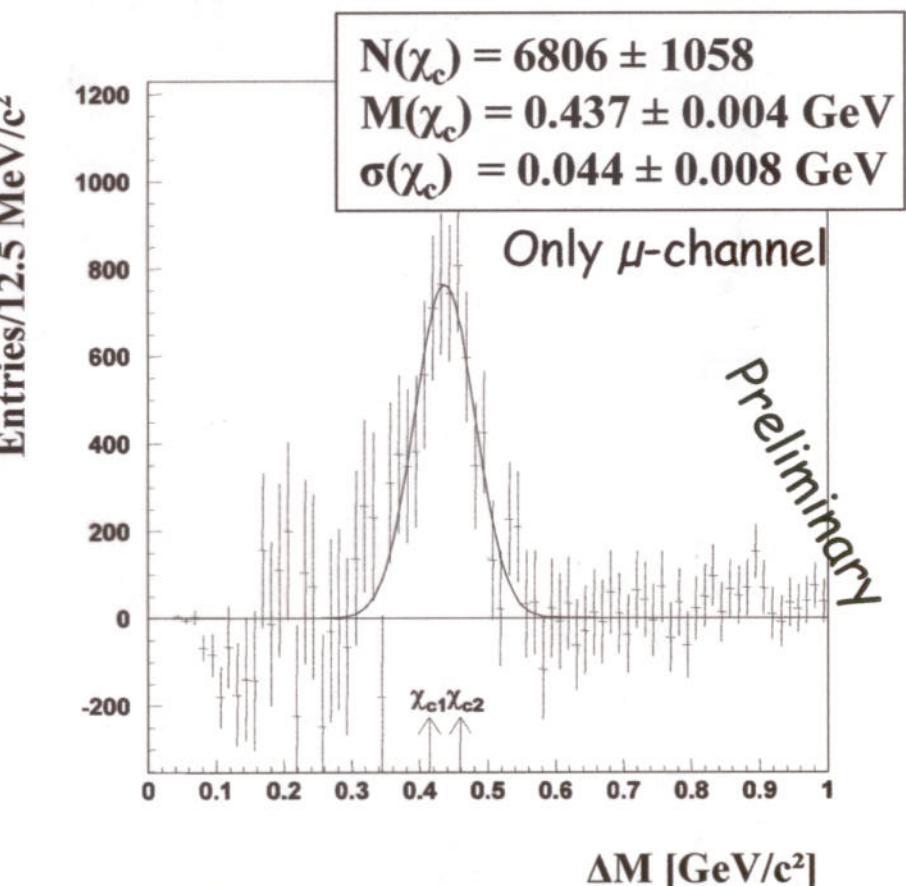
Measurement 2000 based on
 $380 \pm 74 \chi_c$

$$R_{\chi_c} = 0.32 \pm 0.06_{\text{stat}} \pm 0.04_{\text{sys}}$$

Vaia Papadimitriou (Texas Tech University)

$$\Delta M = M(J/\psi \gamma) - M(J/\psi)$$

background subtracted

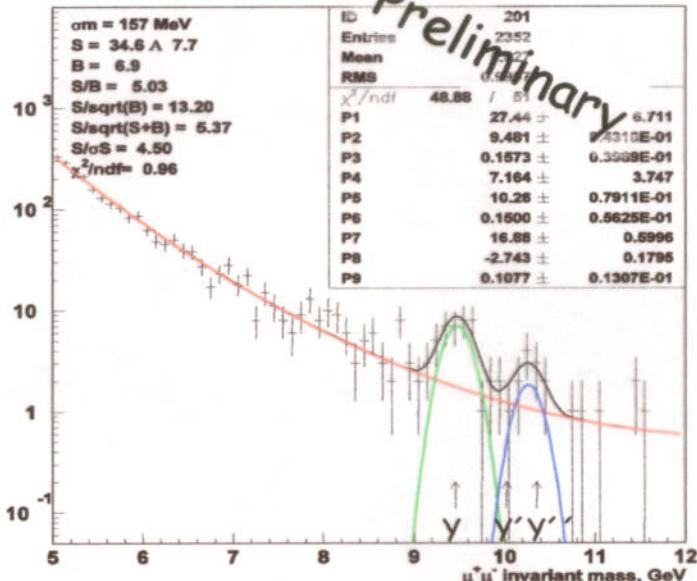


First measurement of χ_c suppression
in nuclear matter possible !

June 28, 2003

Upsilon Production : $\sigma(pA \rightarrow \Upsilon)$

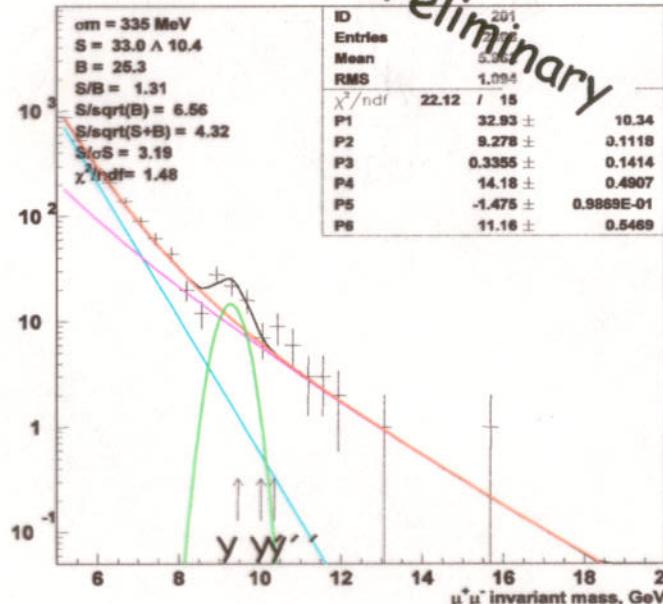
$\Upsilon \rightarrow \mu^+ \mu^-$



Υ events 35 ± 8

Width 157 MeV

$\Upsilon \rightarrow e^+ e^-$



Υ events 33 ± 10

Width 335 MeV

Width : in agreement with MC

Measurement of the Υ production cross section is feasible
 may help to distinguish between Fermilab measurements

Existing measurements by
 E605, E771
 contradictory

Conclusions

- Tevatron Run I analyses done, most HERA-I analyses too
- Lots of results, many surprises
- Very fruitful interaction with theoretical developments
 - ◆ Non-relativistic QCD / colour octet contributions / ...
 - ◆ Soft Colour Interactions, Two Pomerons, ...
- Tevatron Run II will provide $(1.4\text{-}9.0) \text{ fb}^{-1}$ (14-90x statistics)
- HERA-II will deliver $\textcolor{blue}{< 1} \text{ fb}^{-1}$ (10x statistics, measure at larger Q^2 , p_T , polarization)
- A lot of answers and surprises awaiting!!